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Abstract

This document presents advanced models and revises the DynaLearn curriculum for environmental science. The models handle fundamental domain knowledge, describe mechanisms that explain how things work and integrate concepts from environmental science and other domains. This approach adds more complexity to the models, both from the contents and from the modeling point of view, and provides formal explanations for the system behavior. Fundamental principles of a general theory of ecology are associated to the model contents, and further contribute to the development of topics in the curriculum.

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1. Introduction

Advanced models, according to the deliverable D6.3 (Noble *et al*. 2011), should…

- handle fundamental domain knowledge, basic laws and principles that support a bulk of knowledge addressing a large part of the environmental science domain;
- describe mechanisms that explain how things work, on top of which more complex phenomena can be built up and integrate different parts within the environmental science domain and with knowledge from other domains;
- bring more complexity to the model, including mechanisms of control, such as feedback loops, and creating representations of laws and first principles so that the models support the development of formal explanations for the system behavior;
- include more elements on the model and as such better explore the software capabilities.

This Deliverable presents a set of 8 advanced models and a reflection about the topics they address in the curriculum designed in the Deliverable D6.1 for DynaLearn (Salles *et al.*, 2009), based on the ecological theory that supports the knowledge captured by the models.

According to Scheiner and Willig (2008) a theory is a framework or a system of concepts and propositions that provides causal explanations for phenomena within a particular domain. The purpose of a theory is to provide a set of linkages for observations and lower-level models or theories about those observations. These authors recognize three levels of theory: general theory, constituent theories and models, that are seem as specifications of constituent theories.

A general theory consists of an entire domain of science (such as the theory of evolution) and a set of fundamental principles. Such a general theory does not make specific predictions, but provides the scaffolding on which constituent theories are assembled and integrated. The fundamental principles for a general theory of ecology, according to Scheiner and Willig (2008) are:

1. Organisms are distributed in space and time in a heterogeneous manner;
2. Organisms interact with their abiotic and biotic environment;
3. The distribution of the organisms and their interactions depend on contingencies;
4. Environmental conditions are heterogeneous in space and time;
5. Resources are heterogeneous in space and time;
6. All organisms are mortal;
7. The ecological properties of species are the result of evolution.

At the intermediate level are constituent theories, which set boundaries and identify parameters for particular interest, guiding model development. Constituent theories can overlap in domain and differ in scope. Depending on the form and domain of a constituent theory, it may make no predictions, or it may make qualitative predictions. Most important, a constituent theory unifies a set of interrelated models (Scheiner and Willig, 2008).

Some of the constituent theories are at the same level as the ‘laws’ identified by Dodds (2009). Based on the Webster’s Dictionary definition, this author defines laws as a “mechanistically based or self-evident statement of an order or relation of ecological phenomena that holds under ecological constraints”; it provides theoretical basis for a study, and can become the basis for new areas of research (Dodds, 2009).

Still with the Webster’s, Dodds (2009) defines ‘mechanism’ as a fundamental physical, biological or chemical process involved in or responsible for an action, reaction or other natural phenomenon. Fundamental mechanisms provide causal explanations. This is the main goal of the advanced models described in this Deliverable D6.4.1.

Taking these guidelines into consideration, we selected some models already presented in the Deliverable D6.2.1 (Salles *et al*. 2010) to review and better explore, searching for theoretical foundations and basic mechanisms that provide causal explanations to relevant environmental phenomena. Among them, only models in LS4, LS5 and LS6, having these 4 main features, can be classified as advanced, leaving aside models developed in LS1-LS3.

Exploring theoretical aspects would provide a stronger basis for educational uses of the qualitative models produced in DynaLearn. Therefore, the curriculum presented in D6.1 is revisited and illuminated by the advanced model-based approach, as explained in the next section.

2. Advanced models and topics

The following Table provides an overview of themes and topics addressed in advanced models developed by FUB.

Table 2.1. Summary of themes and topics assigned to FUB in the D6.1 and the advanced topics and models covered by FUB in this Deliverable D6.4.1.

Theme	Topic	Subtopic	Learning Space
ESR	Ecological services	Pollination	1 (LS6)
TWL	Conservation biology	Farming *Cerrado*	1 (LS6)
		Introduction of non-native species	1 (LS6)
	Metapopulation	Metapopulation	3 (LS6)
ERC	Sustainable sources and use of energy (wind)	Wind Power	1 (LS6)
P	Pollution mitigation	Phytoremediation	1 (LS6)

2.1. Advanced models evaluation

During the internal model evaluation, partners involved in WP6 agreed upon a questionnaire to be answered that would help the modeler while improving the model and explicating the revision in the respective curriculum topic.

In order to be considered an advanced model, the following questions should be answered:

Are the models...

(1) Scientifically valid representations of environmental issues?

(2) Representations of fundamental ecological knowledge?

(3) Able to demonstrate fundamental mechanisms and able to show fundamental knowledge?

(4) Able to explicate basic questions about fundamental ecological mechanisms?

(5) Able to address relevant processes involved in fundamental ecological phenomena?

(6) Making use of meaningful quantity spaces?

(7) Insightful and clear causal representations of relevant issues following a qualitative systems paradigm?

(8) Clearly showing why a systems perspective is so valuable?

(9) Able to adequately express complexity using different features of each LS?

(10) Able to support what is available in DL from a technical and functional point of view?

Considering also that in the deliverables D6.4.x we have to link the curriculum topics to the models, we could answer if the advanced models...

(11) have clear (content) pedagogical targets.

(12) can be used within local educational frameworks for environmental education:

- linked to local curricula.
- or at least available in a form, to be used along with local curricula (e-learning platforms, defining time needed, proposed activity and educational targets).
- linked to the defined educational goals of environmental education frameworks (EU, local).

3. Advanced curricula aspects

Some of the fundamental principles presented in section 1 are unique to the ecology domain (# 1, 2, 3), while others are shared with other domains (# 4, 5, 6 and 7). All of them may be of interest for educational purposes, but principles shared with other domains provide extra motivation for interdisciplinary work on environmental science in educational contexts. Below, the seven fundamental principles are reviewed under these aspects.

3.1. Principles that are unique to the ecological domain

A fundamental principle that is unique to a domain must meet one of two criteria:

1 - Either the principle is shared by many constituent theories within the domain (the inclusionary rule), or;

2 - The principle is necessary for distinguishing competing general theories (the exclusionary rule).

Inclusionary principles must be broad, as it is the case of the fundamental principles #1 and #2. The first fundamental principle— “Organisms are distributed in space and time in a heterogeneous manner” — is a sort of definition of the domain of ecology, as it is found in textbooks, e.g., Krebs (1994): “the scientific study of the interactions that determine the distribution and abundance of organisms”. As put by Scheiner and Willig (2008), “it encompasses the basic object of interest and its most important property. The heterogeneity of distribution is one of the most striking features of nature: all species have a heterogeneous distribution at some, if not most, spatial scales. Arguably, the origins of ecology as a discipline and the first ecological theories can be traced to its recognition.” Of course, most of lessons and courses in ecological and environmental science are related to abundance and distribution of organisms on Earth.

The second fundamental principle — “Organisms interact with their abiotic and biotic environment” — is the result of the vast majority of ecological processes responsible for heterogeneity in time and space. Many definitions of ecology are equivalent to this principle, within which specific interactions (e.g. competition), that are part of constituent theories, open up interactions with the general theory.

Exclusionary principles (#3), in turn, may be narrow and can often be the result of the history of debates about a theory. The third fundamental principle — “The distribution of the organisms and their interactions depend on contingencies” — has gained growing recognition as one of the most important cause of the heterogeneous distribution of organisms, both at very large extents of time and space (e.g., a particular species that evolved on a particular continent) and at very small extents (e.g., a seed lands in one specific spot and not in another). To show the possible outcomes of a particular situation, it is important to introduce a new component, the calculation of probabilities associated to the occurrence of specific situations.

3.2. Principles that are shared with different domains

If a fundamental principle is shared with another domain, it must be a consequence of mechanisms from another domain and have domain-specific causal significance. Scheiner and Willig (2008) refer to this criterion as the causal rule. Note that the fundamental principles themselves are not independent causal mechanisms. Instead, observed phenomena result from the interaction of the mechanisms that they encompass (Scheiner and Willig, 2008).

This is the case of principles # 4, 5, 6 and 7. The fourth fundamental principle— "Environmental conditions are heterogeneous in space and time" — is a consequence of processes from the domains of the earth and space sciences. These processes are related to local changes in temperature, humidity, light or to seasonal climate variation. These processes are the result of orbital properties of the Earth, whereas a number of different geophysical processes create heterogeneity in environmental elements such as nutrient concentration in the water or on the soil, or the distribution of chemical elements among different types of rocks. Such variation may be associated to interesting biological adaptations. These examples illustrate how a fundamental principle captures a wide range of theories and mechanisms and provides a unifying framework. A number of models can be created on the basis of this fundamental principle, and consequently, several lessons and course plans can be developed for environmental science teaching.

The fifth fundamental principle— "Resources are heterogeneous in space and time" — is also related to processes from Earth and space sciences. In this case, a relevant difference is the reference to the finite nature of these resources. For biological communities this condition may create a competition pressure that has the potential for deep changes in the species composition or importance.

The sixth fundamental principle — "All organisms are mortal" — is the result of processes that come from the domain of organismal biology, physiology, and development. This principle, associated to concepts such as vulnerability or senescence, forms the basis of a large number of constituent theories concerning phenomena as life histories, behavior, demography, and succession.

The seventh principle — “The ecological properties of species are the result of evolution” —is the result of processes that derive from the theory of evolution. Since Darwin, the relation between evolution and ecology has become clear. Nowadays, the ecological and evolutionary processes are better understood, and became the basis for the modern biological thinking. Although among the public other theories have been discussed, within the scientific community the old adagio by Theodosius Dobzhansky (1973), “*nothing in biology makes sense except in the light of evolution*” still is an important background to ecological understanding, and should also be the basis for science education.

As educational activities based on DynaLearn explore cause-effect relations to support predictions and causal explanations, and recognizing that fundamental principles are not independent causal mechanisms, it is important to note that educational goals should focus on the interactions between the causal mechanisms associated to the fundamental principles applied to curriculum topics.

This Deliverable is organized as follows: in section 4, the model *Pollination* is presented and discussed. Initially, the topic in the curriculum associated to the model and the model metadata are presented; next, the rationale and the background provided by the literature are discussed, and followed by the model description, which include the key concepts addressed, the model goals, the modelling approach that justifies why the model can be considered advanced and details about the model ingredients; the following subsection presents the model expression(s), selected scenarios and simulations; finally, a brief discussion about the curriculum topic and the final conclusions are presented. This organization is applied to all the model descriptions. In section 5, the model *Farming Cerrado* is discussed, and in the section 6, the model *Introduction to non-native species* is presented. The models about *Metapopulation* are discussed in section 7, and in section 8, we present the model *Wind power*. The model *Phytorremediation* closes the presentation of advanced models in section 9. Finally, in section 10 we present our conclusions.

4. Pollination

4.1. Topic and model metadata

Topic	Ecological services		
Authors	Gustavo Leite Isabella Sá Paulo Salles Adriano Souza	**Version(s)**	vs1
Models	Pollination LS6.hgp		
Target users	Secondary level students and general public interested in topics and concepts in environmental science.		

4.2. Topic rationale

4.2.1. Background

Little attention has been given to the importance of pollinators and the service they provide in maintaining human needs for food and environment functioning. Recent biodiversity inventory suggests that about 90% of all flowering plants depend on insects, birds, bats, and other animal species to assist in delivering the pollen that they need to create seeds. At least one-third of the crops used for human needs rely on animal pollinators for successful reproduction. The annual value of this ecological service is estimated to be US$ 40 billion. At least 200,000 species of animal play a role in assisting plant reproduction, and the vast majority are wild species, many of which play roles unrecognized by science.

For decades, biologists have been worried about declining populations of both wild and domesticated pollinators. Many factors contribute to pollinator disappearance, including habitat loss, climate change, introduction of exotic species, and the spread of diseases, but one of the most important threats is the indiscriminate use of pesticides, that eliminate beneficial species along with the pests they are intended to target. A great deal of attention has been focused recently on honey bees. These industrious little insects not only make honey, but they play a vital role in fertilizing crops. In fact, their importance in spreading pollen is worth at least 100 times the value of the honey they make. Bee-pollinated foods include squash, tomatoes, peppers, apples, and pears. Farmers pay commercial beekeepers to bring hives to their fields to pollinate crops. Unfortunately, there is a shortage of honeybees.

Native pollinators are just as important for crops as domesticated ones. So, the problem with pesticides is that they are an important tool in disease prevention, food preservation and property protection. On the other hand, the battle against biological enemies often has unintended consequences. So it is needed more thoughtful and sustainable methods.

4.3. Model

4.3.1. Concepts and goals

The goal of this model is to demonstrate the role of pollination and pollinators in agricultural production and how the use of enemies control based on pesticides affect this important ecological service.

The key issues and concepts involved in pollination process are the following:

- Pollination is an important process that involves the transfer of pollen among flowers, mediated by the wind, water and animals, mostly insects.
- Pollinator disappearance can be caused by habitat loss, climate change, and introduction of exotic species, spread of diseases and the use of pesticides.
- As farmers use pesticides to fight plagues in agriculture, they involuntarily kill pollinators and, because of that, they cause a decrease in their own production.

After a certain level of pollinator loss, agriculture finds itself in serious trouble, with significant productivity reduction and low revenue.

4.3.2. Modeling approach

This model handles with fundamental domain knowledge and it is able to describe events or mechanisms that explain how some human actions, like deforestation, can affect, for example, agricultural production through pollinators lost.

4.3.3. Model ingredients

Table 4.1. Entities, quantities and quantity spaces involved in the Pollination model.

Entity	Quantity	Quantity Space
Human activity	Investment	*{Zero, Low, Medium, High}*
	Agricultural production	*{Zero, Low, Medium, High}*
	Revenue	*{Zero, Low, Medium, High}*
	Pesticide use	*{Zero, Low, Medium, High}*
	Deforestation rate	*{Zero, Plus}*
Ecological service	Pollination	*{Zero, Plus}*

Native bee	Number of	*{Zero, Low, Medium, High}*
Plant	Number of	*{Zero, Low, Medium, High}*
	Seed mortality	*{Zero, Plus}*
	Seed	*{Zero, Low, Medium, High}*

4.4. Model expression

4.4.1. Scenarios and simulations

Scenarios represent initial situations, including configurations of the system of interest, and initial values of the quantities. The most complete scenario in this work is shown in Figure 4.1.

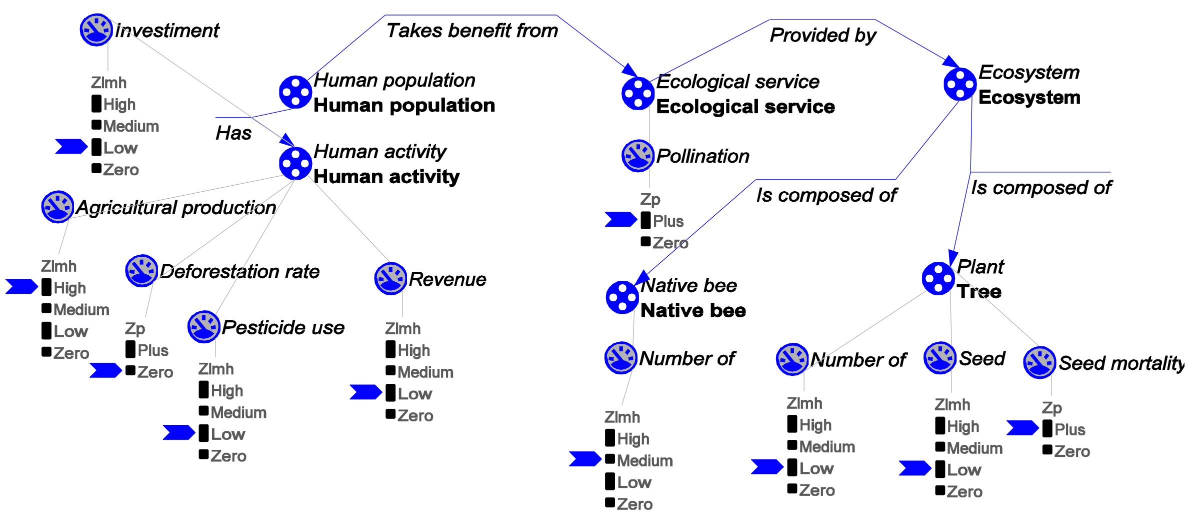


Figure 4.1. Scenario "Sce02 High agricultural production effects" with initial values.

The full simulation of this scenario presents a behavior graph with 10 states (Figure 4.2). In a general way, the model shows the effect of forest cover removal in natural environments near agricultural lands, as well as pesticide use in pest control and agricultural production enhancement, where decreasing the number of trees and increasing pesticide use are directly reflected on amount of pollinators (e.g. native bees). The path selected in this simulation goes through the following states: [2 → 3 → 4 → 5 → 6 → 7 → 8 → 9 → 10]. A diagram showing the causal dependencies in the model is in the Figure 4.3.

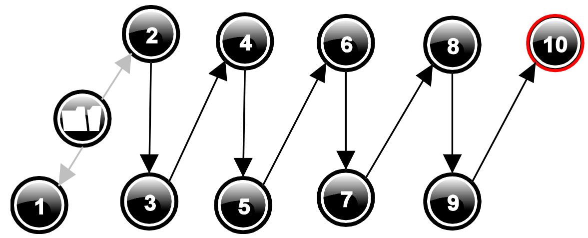


Figure. 4.2. State graph – sce02 high agricultural production effects.

Due pesticide use and reduction in number of trees, the number of native bees decreases affecting indirectly pollination ecosystem service that is related with number of bees by direct proportionality [P+(Pollination, Number of)]. Despite they are not related by proportionalities, reduction in pollination leads to decrease in the number of seeds [I+(Seed, Pollination)], because the last one is the result of difference between the amount of fecund seeds (Pollination) and the amount of dead seeds (Seed mortality). Reduction in number of bees leads the number of fecund seeds to the same direction [P+(Pollination, Number of)], that on the other hand determine agricultural production and revenue to decrease.

The value history diagram obtained from the simulation of this scenario can be seen in Figure 4.4.

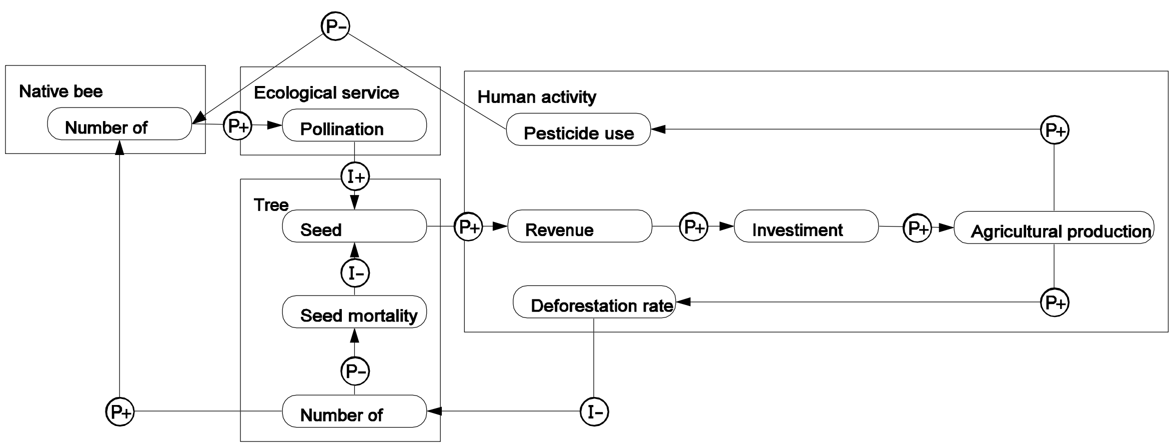


Figure 4.3. Causal model State 10 – sce02 high agricultural production.

The reduction in number of fecund seeds is propagated to revenue, investment and agricultural production by a direct proportionality [P+(Revenue, Seed), P+(Investment, Revenue), P+(Agricultural production, Investment)], making these variables achieve their smaller values (Zero) in the last state.

The effects of reduction in agricultural production are reductions in pesticide use and in the deforestation rate [P+(Pesticide use, Agricultural production), P+(Deforestation rate, Agricultural production)], closing the feedback cycle in state 10, in which use of pesticide, deforestation and agricultural production tend to Zero value, which allows reestablishment of number of bees to Medium value.

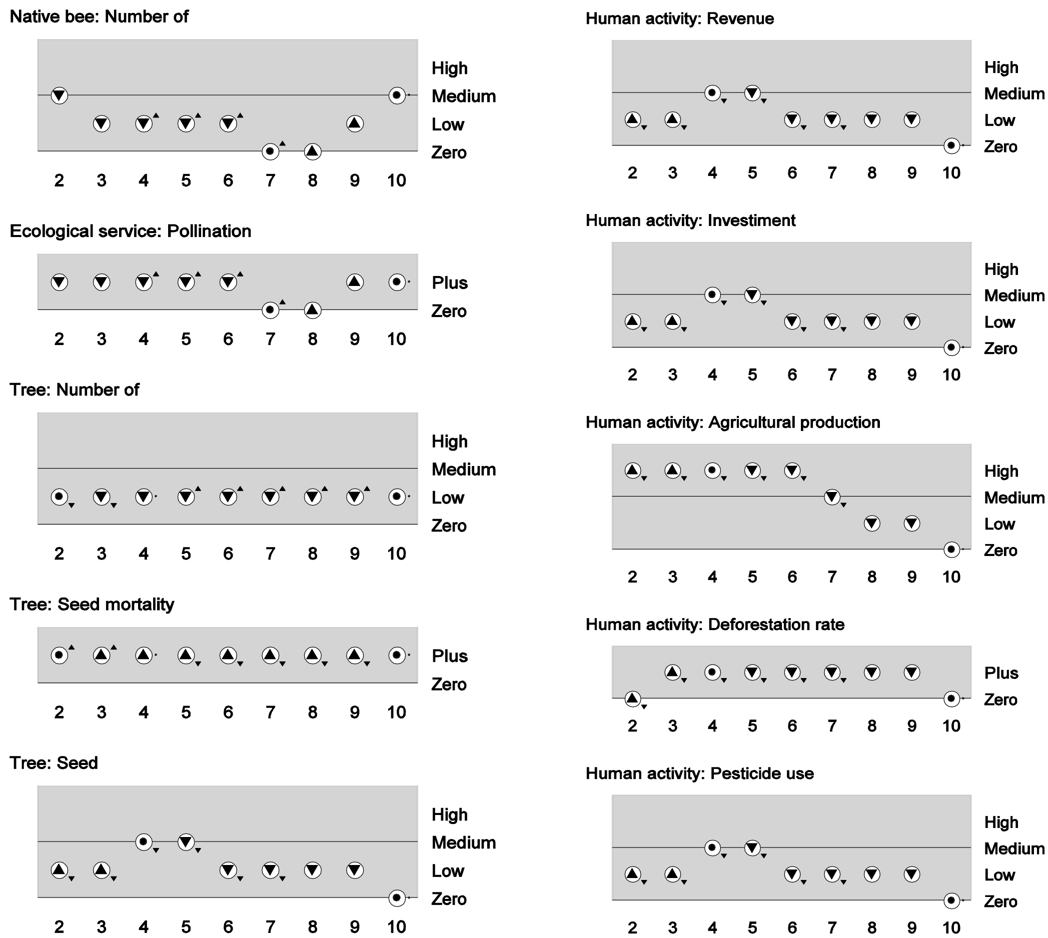


Figure 4.4. Value history diagram for simulation of Scen02 high agricultural productivity effects

4.5. Theoretical aspects of the model and topic

Laws and principles addressed in Pollination model:

Remarkable in this model is the inspiration "Evolution affects ecology"

- Principles (Scheiner and Willig, 2008)
  2 (organisms interact with biotic and abiotic factors),
  3 (distribution depends on contingencies)
  6 (all organisms are mortal)

- Laws (Dodds, 2009)
  Dominance of the Homo sapiens
  Laws from economics
  Fundamental properties of populations (limits to growth, extinction probability)
  Biotic and abiotic interactions (species interactions)
  Evolution affects ecology

4.6. Conclusion of the topic

The model is relatively simple, but shows the effects of the use of pesticides on natural pollinators. Simulations present increasingly more details the consequences of killing bees: eventually, the whole system may collapse and no longer be able to produce. This model can be used as a reference model for other researchers and stakeholders to use as decision making or strategy planning tool, or re-use it to create other representations in which pollination is part of the model. Also this model can be used in DynaLearn to provide automated feedback improving and fixing models built in Learning by Modeling activities.

5. Farming *Cerrado*

5.1. Topic and model metadata

Topic	Conservation Biology		
Authors	Gustavo Leite Isabella Sá	**Version(s)**	vs15
Models	Farming Cerrado LS6.hgp		
Target users	Stakeholders and students		

5.2. Topic rationale

5.2.1. Background

A soybean boom is sweeping across South America. Inexpensive lands, availability of new crop varieties and government policies that favor agricultural expansion have made South America the fastest growing agricultural area in the world. The center of this rapid expansion is the *Cerrado*, a huge area of grassland and tropical forest, stretching from Bolivia and Paraguay across the center of Brazil, almost to the Atlantic Ocean. Biologically, this rolling expanse of grasslands and tropical woodland is the richest savannah in the world, with at least 130.000 different plant and animal species, many of which are threatened by agricultural expansion.

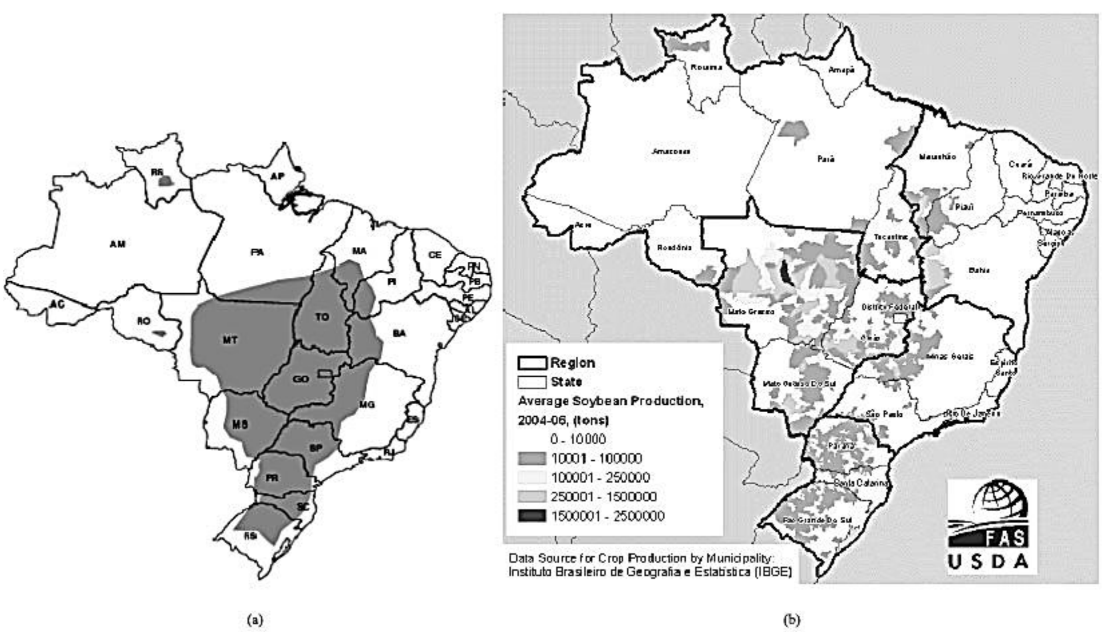


Figure 5.1. Map of soybean production in Brazil. (a) The *Cerrado* Biome in Brazil; (b) Incidence of soybean production (2004-06). Source: USDA (2008)

In the past few decades, farmers have learned that modest application of lime and phosphorus can quadruple yields soybeans, maize, cotton, and other valuable crops. Researchers have developed more than 40 varieties of soybeans – mostly through conventional breeding, but some were created with molecular techniques – specially adapted for the soils and climate of the *Cerrado*. Until about 30 years ago, soybeans were a relatively minor crop in Brazil. Since 1975, however, the area planted with soy has doubled every four years, reaching more than 25 million ha in 2006. Although that is a large area, it represents only one-eighth of the *Cerrado*, more than half of which is still occupied by pasture (Cunningham and Cunningham, 2007).

Figure 5.2. Percent remaining of Cerrado biome in Brazil (1985-2004). Source: http://news.mongabay.com/2007/0907-cerrado.html

5.3. Model

5.3.1. Concepts and goals

Understand how the food demand, boosted by population dynamics, can affect the exploration and substitution of natural environments to cattle areas is of great importance to reflect about the necessity of conscientious consumerism and integration of sustainable management forms.

The key questions and concepts about the effects of the population growth in the *Cerrado* degradation, due to great food demand, are as follow:

- This dramatic increase in South America agriculture helps answer the question of how the world may feed a growing human population.
- Increasing demand for both soybeans and beef create land conflicts in Brazil.

- The pressure for more cropland and pasture is a leading cause of deforestation and habitat loss, most of which is occurring in the ‘arc of destruction’ between the *Cerrado* and the Amazon forest (Fig. 5.3).
- The rapid expansion and mechanization of agriculture in Brazil is destroying biodiversity and creating social conflicts, as people move into formerly pristine lands.

Figure 5.3. Deforestation air view of a region destined to the expansion of soybean culture in the Brazilian *Cerrado*. Source: http://www1.folha.uol.com.br/ambiente/880951-embrapa-veta-cientistas-em-seminario-sobre-codigo-florestal.shtml

5.3.2. Modeling approach

This model can be used as reference and inspirational source to questions as: what is the effect of the farming expansion over the deforestation? How the increase in human population can affect the natural vegetation? The main goal of the model is represent the population growth effect in the *Cerrado* degradation, due to a crescent food demand. So, this model captures the basic processes and mechanisms of this dynamic and is a valuable tool to be used by environmental managers.

5.3.3. Model ingredients

Table 5.1. Entities, quantities and quantity spaces involved in the Farming *Cerrado* model.

Entity	Quantity	Quantity Space
Human population	Agricultural production	*{Zero, small, medium, large}*
	Demand for export	*{Zero, low, medium, high}*
	Economic growth rate	*{Minus, zero, plus}*
	Revenue	*{Zero, low, medium, high}*
	Size	*{Zero, small, medium, large}*
Cerrado	Cattle	*{Zero, small, medium, large}*
	Deforestation rate	*{Minus, zero, plus}*
	Grains	*{Zero, small, medium, large}*

Open areas	*{Zero, small, medium, large}*
Pasture area	*{Zero, small, medium, large}*
Soybean cultivation area	*{Zero, small, medium, large}*

5.4. Model expression

5.4.1. Scenarios and simulations

The current version of the model is built in 15 model fragments that are simulated for one scenario (Fig. 5.4).

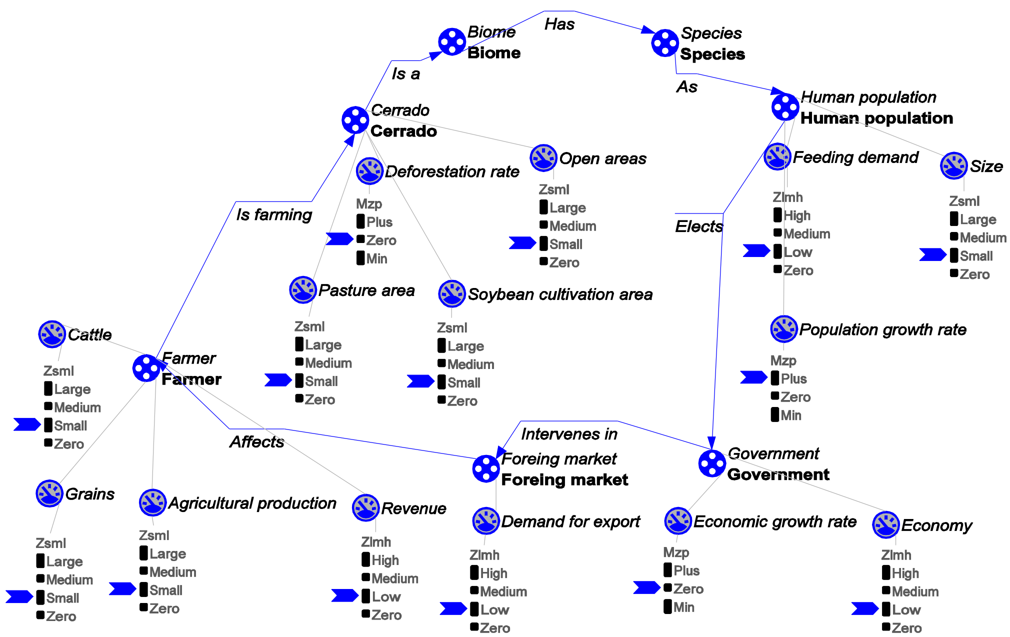


Figure 5.4. Sce01 “Population growth affects feeding demand” with initial values

The simulation starting with this scenario produces one initial and one end state, [1] and [5], respectively, and the full simulation using Fastest Heuristic Path has 5 states (Fig. 5.5). The causal model produced by the state 5 is shown in the Figure 5.6.

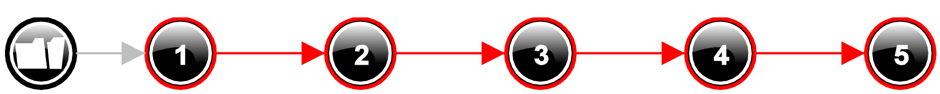


Figure 5.5. State graph obtained in a simulation with Sce01 “Population growth affects feeding demand”

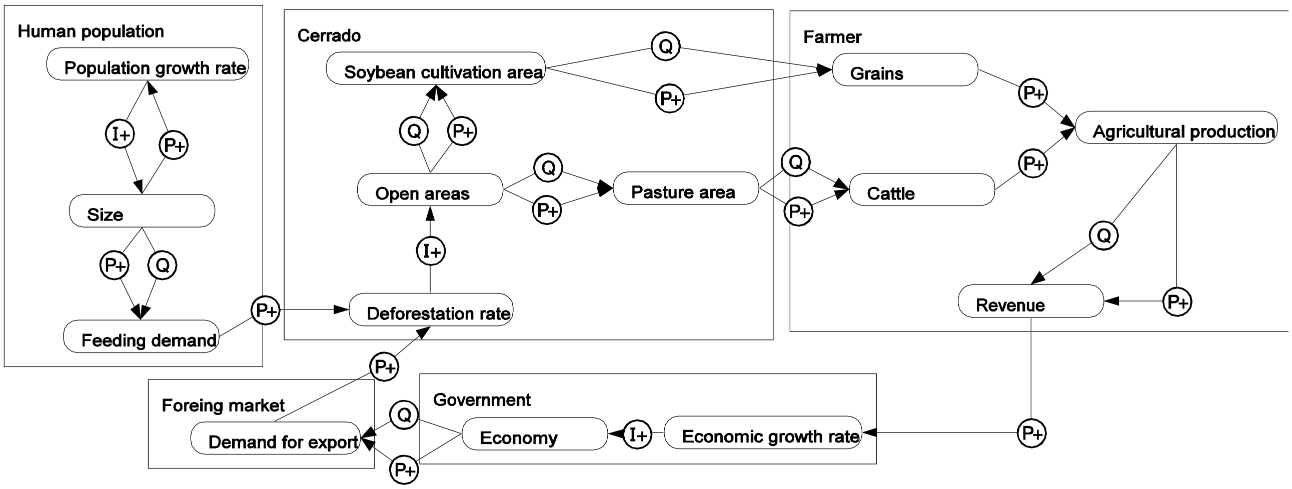


Figure 5.6. Causal model State 5 – sce01 “Population growth affects feeding demand”

This way, Figure. 5.7 shows the increasing size of the *Human population* due to the positive initial value of Population growth rate; this trend propagates to Feeding demand and is further reflected on Deforestation rate. The consequence is the increase in Open areas. The opening of new areas for farming allows Pasture area and Soybean cultivation area to increase food production (Cattle and Grains). Increasing Agricultural production stimulates Economy growth rate, which causes Economy to grow and generate Revenue for the population. Economic factors work as a driving force on the Demand for export to increase, closing the loop with the pressure for opening up new areas for increasing food production. A relevant behavior path to illustrate the above description is [1 → 2 → 3 → 4 → 5].

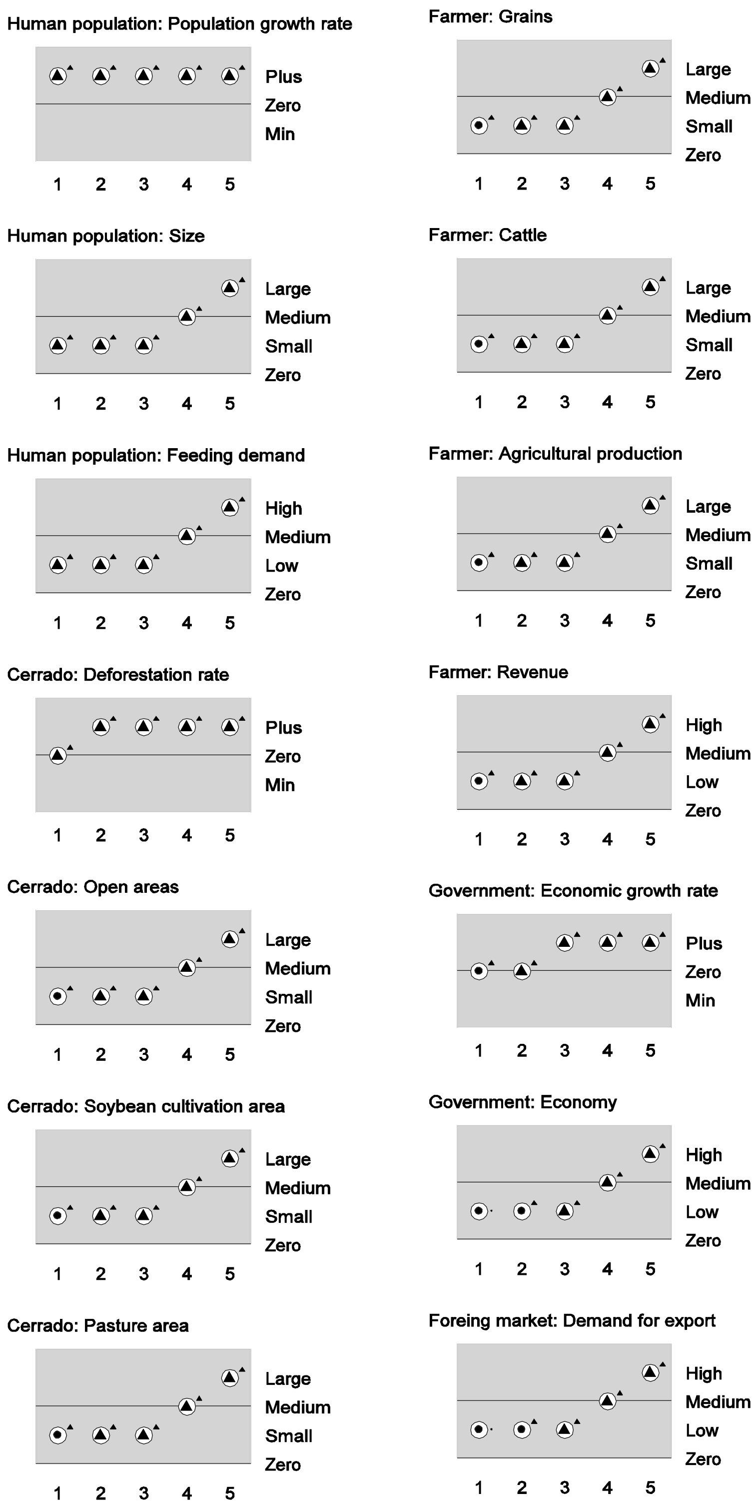


Figure 5.7. Value history diagram of selected quantities obtained in a simulation starting in scenario 01 “Population growth affects feeding demand”

5.5. Theoretical aspects of the model and topic

Laws and principles addressed in Farming *Cerrado* models:

Remarkable in this model is the inspiration “Dominance of the Homo sapiens”

- Principles (Scheiner and Willig, 2008)
  1 (distribution in space and time is heterogeneous),
  2 (organisms interact with biotic and abiotic factors),
  3 (distribution depends on contingencies)
  4 (environmental conditions are heterogeneous in space and time)

- Laws (Dodds, 2009)
  Ecological diffusion (osmosis-like model; passive movement)
  Dominance of the Homo sapiens
  Laws from economics
  Metapopulation (fragments of population, patch/matrix)
  Scaling (local and regional)

5.6. Conclusion of the topic

This model provides a simplified view of the mechanism of land use change. The model demonstrates the replacement of natural areas by agricultural land, opening new areas for food production to supply a growing human population. This way, the model explains how the influences work in the system, allowing a better understanding on how to control these processes. Further development of the model could improve the representation of land use change effects on the ecosystem.

6. Introduction of non-native species

6.1. Topic and model metadata

Topic	Conservation Biology		
Authors	Gustavo Leite Adriano Souza Paulo Salles	Version(s)	vs1
Models	Introduction of non-native spp LS6.hgp		
Target users	Stakeholders, researchers and students		

6.2. Topic rationale

6.2.1. Background

A definition found in Wikipedia for introduced species is as follow: “An introduced, neozoon, alien, exotic, non-indigenous, or non-native species, or simply an introduction, is a species living outside its native distributional range, which has arrived there by human activity, either deliberate or accidental. Some introduced species are damaging to the ecosystem they are introduced into, others have no negative effect and can, in fact, be beneficial both to humans - as an alternative to pesticides in agriculture for example - and to Ecosystems - as in New Zealand where introduced species of flora from North America have been shown to increase Biodiversity and Bioproductivity” (Introduced species, 2011). However, the second biggest cause of biodiversity loss in the planet is the invasion of natural environments by exotic species (GISP, 2005). According to the definitions adopted by the International Convention of Biologic Diversity (CDB, 1992) in the 6th Conference of Parts (COP-6, Decision VI/23 2002), a species is considered exotic (or introduced) when situated in a different place of its natural distribution, because of the mediated introduction, voluntary or involuntary, by human actions.

Intentional introductions of species are motivated by many reasons that touch slightly in social, economic and even environmental ends. In freshwater environments, attention must be paid to the introduction of fish for breeding or fishery increment. Molnar *et al.* (2008) had compiled information from over 350 data sources. Their database now includes 329 marine invasive species, with at least one species documented in 194 ecoregions (84% of the world’s 232 marine ecoregions; Figure 6.1). In Figure 6.2, we have examples of an animal invasive species, the North America beavers, in Tierra del Fuego. There, they cause great impacts on landscape and local ecology through their dams. The other example shown in Figure 6.2 is Kudzu, a Japanese vine species which has a status of invasive in the southeast of United States, growing in Atlanta, Georgia. It is now common along roadsides and other undisturbed areas throughout most of southeastern United States, where it has been spread at a rate of 61,000 ha annually (Invasive species, 2011; Kudzu, 2011).

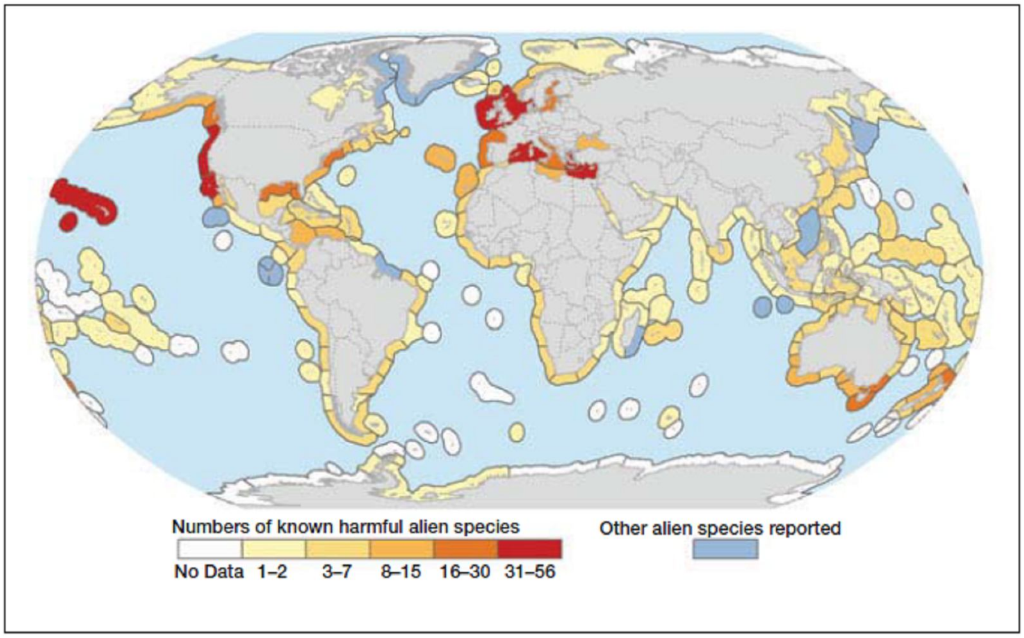


Figure 6.1. Map of the number of harmful alien species by coastal ecoregion. Source: Molnar *et al*. (2008).

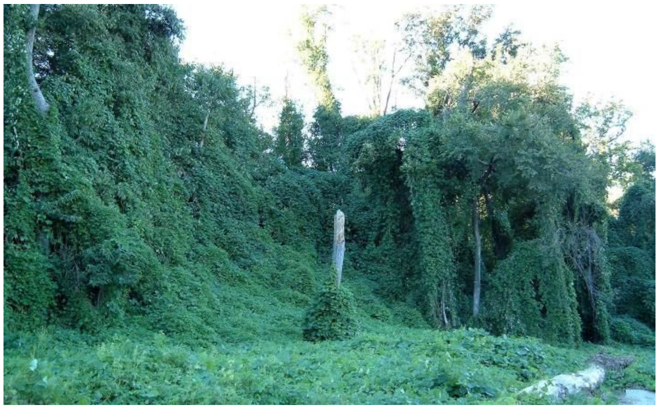


Figure 6.2. Beaver dam in Tierra del Fuego (A) and Kudzu on trees in Atlanta, Georgia (B). Source: (Invasive species, 2011).

6.3. Model

6.3.1. Concepts and goals

The goal of this model is to demonstrate the species-based mechanism of invasion, the effects of any exotic species population introduction in the population of any native species.

The key issues and concepts for explaining the dynamics of invasion or introducing of non-native species are the following:

- Introduction or transference of exotic species can provoke many changes in the environment where the species is introduced.
- Most of the environmental changes occurring after the introduction are related, among others, to depletion or even extinction of native stocks, alteration of the host habitat, competition pressures, and predation.
- The occurrence of invasive alien species can reduce the reproductive success of native species and produce negative socioeconomic impacts.
- An introduced species might become invasive if it can outcompete native species for resources, such as nutrients, light, physical space, water or food. If these species evolved under great competition or predation, the new environment may allow them to proliferate quickly.

6.3.2. Modeling approach

This model can be used as a reference model for other people, mainly researchers and students interested in knowing about invasive population species behavior and to use as source of inspiration to create other representations and scenarios. The main objective of this model was to represent the species-based mechanism of invasive species, i.e. the effect of an introduced population on a native population. This way, the model is able to capture the basic mechanism of species invasion and constitute a basic knowledge of a very interesting and often harmful phenomenon.

6.3.3. Model ingredients

Table 6.1. Entities, quantities and quantity spaces involved in the Introduction of non-native spp model.

Entity	**Quantity**	**Quantity Space**
Native population	Size	*{Zero, Low, Medium, High}*
	Birth rate	*{Zero, Plus}*
	Death rate	*{Zero, Plus}*
	Reproductive success	*{Zero, Plus}*
	Agressiveness	*{Zero, Plus}*
	Resource access	*{Zero, Low, Medium, High}*
Exotic population	Size	*{Zero, Low, Medium, High}*
	Birth rate	*{Zero, Plus}*
	Death rate	*{Zero, Plus}*
	Reproductive success	*{Zero, Plus}*
	Agressiveness	*{Zero, Plus}*
	Resource access	*{Zero, Low, Medium, High}*
	Predation pressure	*{Zero, Plus}*
Human activity	Rate of introduction of exotic spp	*{Zero, Plus}*

6.4. Model expression

6.4.1. Scenarios and simulations

The current version of the model has 5 scenarios; the more complex scenario (Scen05 all influences) is presented in Figure 6.3. This scenario shows the relation between two species populations, one of them native and the other one exotic, introduced by human activities, being the exotic a predator of native population.

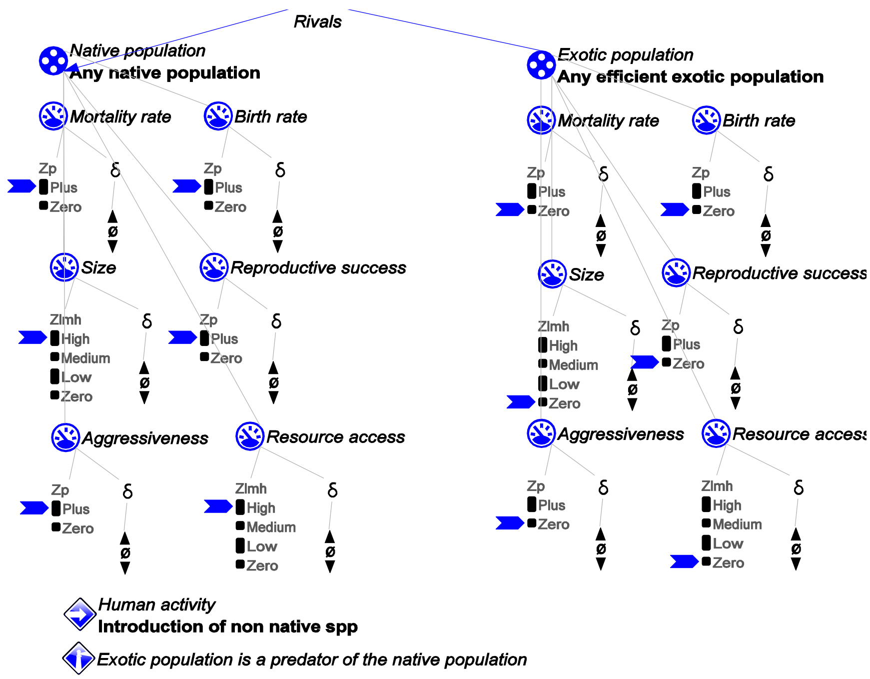


Figure 6.3. Scenario "Sce05 all influences" with initial values, agents and assumptions.

The simulation with the scenario "Scen05 all influences" is presented in Figure 6.4 and produced a behaviour graph with 31 states.

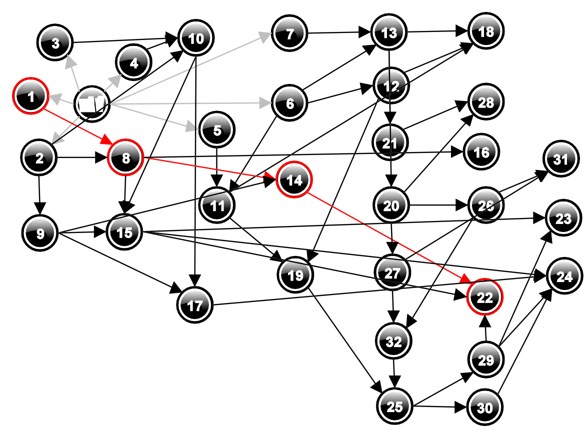


Figure 6.4. State graph obtained in a simulation with the scenario Sce5 all influences.

The causal model obtained in state 31 of the simulation can be observed in Figure 6.5. Overall, the simulation shows the effects of introduction of populations of exotic species through predation pressure influencing mortality rate of a native population species, and how aggressiveness increases the resource access of exotic population species to the detriment of resource access of native species population.

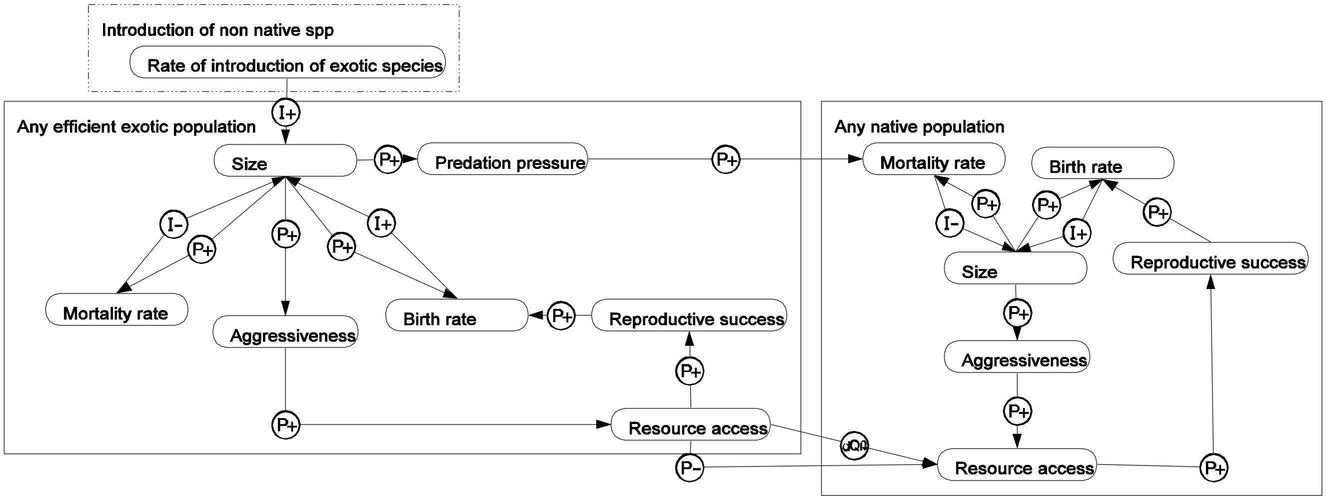


Figure 6.5 Causal model obtained in a simulation with the scenario sce05 all influences, state 31.

The influences operating in the causal model determine the behavior of the system, captured in the value history diagrams of the quantities shown in Figure 6.6.

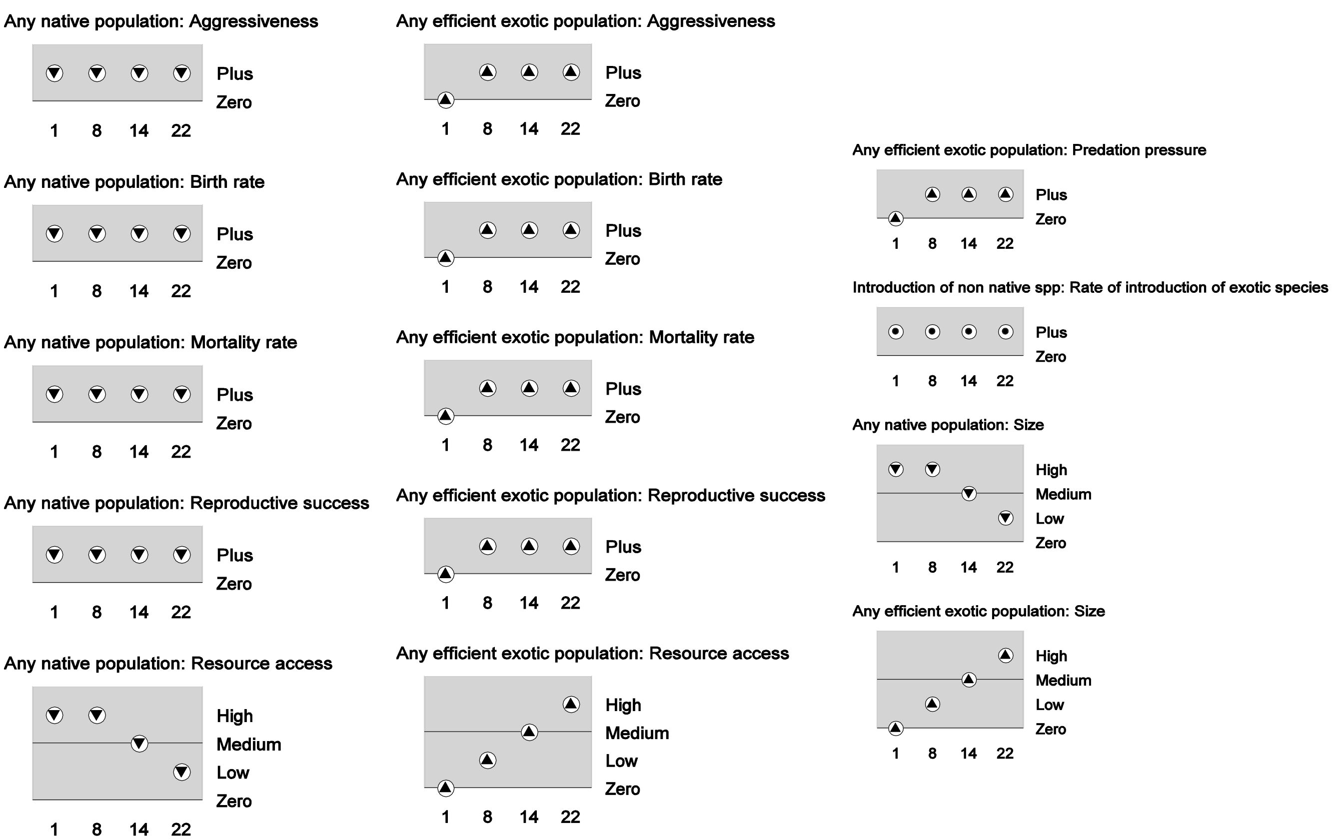


Figure 6.6. Value history diagram of the quantities obtained in a simulation starting in scenario Sce05 all influences

6.5. Theoretical aspects of the model and topic

Laws and principles addressed in Introduction of non-native species model

Remarkable in this model is the inspiration “Species interactions”

- Principles (Scheiner and Willig, 2008)
  1 (heterogeneous distribution of organisms in space and time)
  2 (organisms interact with biotic and abiotic factors),
  3 (distribution depends on contingencies)

- Laws (Dodds, 2009)
  Dominance of the Homo sapiens
  Laws from economics
  Fundamental properties of populations (limits to growth, extinction probability)
  Biotic and abiotic interactions (species interactions)
  Diversity correlates with area

6.6. Conclusion of the topic

The dynamics of invasive species and the effects of introduction of non-native species in the environment are emergent fields of scientific investigation, with impacts on socioeconomic aspects of the environment. Modeling systems where non-native species were introduced contributes to the understanding of drivers and magnitude of changes. The model presented here shows that introduction of a non-native species population that becomes a predator of any native species population causes a decrease in the resource access and population size of prey species.

7. Metapopulation

7.1. Topic and model metadata

This topic addresses three advanced models in order to represent, explain and compare two main mechanisms designed to explain metapopulation behavior and dynamics. The third model was built to integrate current knowledge about metapopulation theory and its implication for conservation biology. Metadata and descriptions of the three models are presented separately.

Table 7.1. Metapopulation Levins' model metadata

Topic	**Metapopulation**		
Authors	Isabella Sá Paulo Salles	**Version(s)**	Vs05
Models	Metapopulation_dynamics_Levins'_LS6_vs05.hgp		
Target users	Researchers, students and stakeholders		

Table 7.2. Metapopulation source-sink model metadata

Topic	**Metapopulation**		
Authors	Isabella Sá Paulo Salles	**Version(s)**	Vs07
Models	Metapopulation_Source_and_Sink_LS6_vs07.hgp		
Target users	Researchers, students and stakeholders		

Table 7.3. Metapopulation conservation integrated model metadata.

Topic	**Metapopulation**		
Authors	Isabella Sá Paulo Salles	**Version(s)**	vs11
Models	Metapopulation_ Conservation_Integrated_LS6_vs11		
Target users	Researchers, students and stakeholders		

7.2. Topic rationale

7.2.1. Background

A metapopulation consists of a group of spatially separated populations of the same species which interact at some level (Metapopulation - Wikipedia, 2011). The term metapopulation was coined by Richard Levins in 1970 to describe a model of population dynamics of insect pests in agricultural fields, but the idea has been most broadly applied to species in naturally or artificially fragmented habitats (Metapopulation - Wikipedia, 2011). In Levins' own words, it consists of "a population of populations" (Levins, 1969).

A metapopulation is generally considered to consist of several distinct populations together, occupying areas of suitable habitat which are currently unoccupied. In classical metapopulation theory, each population cycles in relative independence of the other populations and eventually goes extinct as a consequence of demographic stochasticity (fluctuations in population size due to random demographic events); the smaller the population, the more prone it is to extinction (Metapopulation - Wikipedia, 2011).

The fundamental idea proposed by Levins (1969, 1970) is the persistence of the metapopulation as a result of the balance between extinction and colonization stochastic processes. Levins considered the metapopulation as a population of local populations, which inhabit a great net of habitat patches. In his model, he represented the variation in the metapopulation size, *P(t)*, as a measure of the fraction of occupied patches in time *t*.

Having the logistic model as a basis, he assumed that the basic entities and quantities of his model have the same behavior. For example, all the patches have the same quality and size. Another important assumption of this classic model: the local dynamics of different subpopulations is asynchronous. Local extinctions happen independently, in different habitat patches (Hanski, 1999). As all populations are equal, they equally contribute to the total of migrants, what is not explicitly represented in the model. Changes in *P* are given by:

$$\frac{dP}{dt} = cP\,(1 - P) - eP$$

in which *c* and *e* are, respectively, colonization and extinction rate.

Levins' model offers a deterministic description of the 'change' rate in the metapopulation size, though the model is implicitly based in local stochastic extinctions. The model assumes that infinite habitat patches can exist and that colonization is not affected by the distance (Hanski, 1999). This is a limitation of the model, since organisms' movements are restricted in space, and that not all habitat patches have the same accessibility. The most important characteristic of the model is that, in the extinction and colonization scale, the local dynamics can be ignored (Donahue and Lee, 2008).

In the model proposed by Levins, the colonization rate depends on the number of occupied patches. The necessary condition for the survival of a unique population in a net of empty patches is that the colonization of at least one patch must occur during its existence (Hanski, 1999). There is a boundary between colonization and extinction rate, which must be attended so that the metapopulation persists. If the local extinction surpasses colonization, the metapopulation will decline (Levins, 1969).

However, in the source-sink model it is considered that the movement or dispersion of propagules between habitat patches is an essential ingredient in metapopulations dynamics (Clobert *et al*., 2004). The dispersion movement can be considered a consequence of the population density in the patch of origin, what also happens due to other characteristics, as patch size and distance between them. The changes in a local population density reflect in the balance of individual's birth and death, and between emigration and immigration fluxes (Kawecki, 2004). The stability and survival of two different populations can rise from a continuous exchange of individuals, even if there is local unbalance between vital rates.

The structure proposed by Pulliam (1988) would be justified as a consequence of the differences between the local quality of each habitat patch (Kawecki, 2004). Usually, the birth numbers are bigger than the death ones in places of bigger quality, what generates an excess of emigrant individuals, which leaks to a smaller quality place, that can become imported patches – sink – of individuals (Pulliam, 1988). The definition of 'source' or 'sink' habitat is based in the difference of emigration and immigration rates. There will be bigger emigration rate in source habitat and bigger immigration rate in sink habitat (Kawecki, 2004).

The dispersion process usually reduces the variation in the local population. Thus, in the good quality patches, the dispersion tends to keep the density below the carrying capacity of the patch (Kawecki, 2004). The idea is that the density of the population, in both patches, after the dispersion process, will be the same. Because of this, the population dynamics that are of the type 'source and sink' is considered, in this work, as analogous to the diffusion or osmosis processes (Dodds, 2009). Consequentially, in an equilibrium situation, the population that is found is the better quality habitat will be below the carrying capacity, and there will be a bigger number or birth than death (Pulliam, 1988), what is compensated by the high rates of emigration.

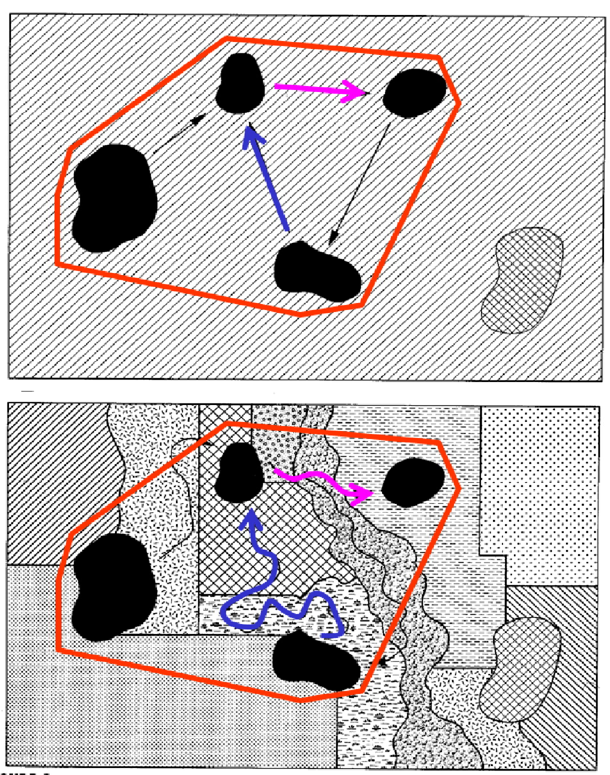
It is important to remember that this model assumes that the generations are discrete, that each individual spend its life, basically, in the same habitat patch and that only the habitat conditions affect its survival and reproduction. The model represents the dispersion relations (emigration and immigrations) in a basic way. However, the existence of habitats of the type source and sink is also result of ecological and evolutional consequences of the environmental heterogeneity (Kawecki and Stearns, 1993).

There are also the cases in which the dispersion process occurs passively, when there is a general tendency to the dispersion (Kawecki, 2004). One possible explanation to the dispersion that happen from a good to a bad quality patch is the fact that for some individuals it is better to try to reproduce in a lower quality patch, than be a 'fluctuant' and 'non-reproducible' member of a source patch, of good quality (Pulliam; Pulliam and Danielson, 1992).

Then, in order to make a better understanding of which of these theories is more suitable of each situation and to make a step forward in metapopulation theory advance, some elements of landscape ecology and conservation biology would be considered.

To study the landscape fragmentation process by means of experiments is hard, because all the landscape is unique, due to its history of modifications and its geomorphological specificity (Lookingbill *at al.*, 2008). There is not the possibility of making replica or control. Such limitation imposes the search of a better understanding of the causality relations that represent the mosaic that is the landscape (see Figure 7.1). In this context, the modeling of the distribution of the species, as proposed by Hutchinson (1957), takes in consideration three main aspects: predation, competition and resources availability.

Figure 7.1. Difference in individuals movement and the meapopulation dynamics in two scenarios: conserved landscape and heterogeneous landscape with different fragmentation processes (adapted from Hanski & Gilpin, 1997).



The variation of the quality of the habitat patch is not directly related to the size of the patch. There is also the influence of the connectivity and other ecological processes. Hanski tested the various premises of Levins' original model and added some different correlations, inspired by landscape ecology. It is considered as landscape any heterogeneous space for a factor of interest (Turner, 2005), or, according to Metzger (2001), it is a mosaic upon which the local ecosystems repeat themselves.

It is valid to point that I. Hanski made, with base in his studies, different important correlations to be added to R. Levins' original model: 1) Correlation between extinction rate and the number of occupied patches; 2) Correlation between the rate and the colonization and the isolation degree of a patch to another. In other words, there is a function that relates the colonization to the distance between the habitat patches (Hanski, 1999); and 3) Correlation between the local extinction rate and the size of the patch.

We report, below (Table 7.4), the different scales of study used in the metapopulation model. It is interesting to note that such scales are not discrete, but continuous, and also structured hierarchically. Many times the habitat patches are not completely delimitated, making harder to define which are local populations (Hanski and Glipin, 1991).

Table 7.4. Three spacial scales explored in the metapopulation model (adapted from Hanski and Gilpin, 1991)

Different study scales
Local scale
Scale in which the individuals move and interact with each other in the course of their routine activities of feeding, hunt and reproduction.
Metapopulation scale (regional)
Scale in which the individuals move with lesser frequency from a place to another (from a local population to another), typically through habitats that are not appropriate for their feeding and reproductive activities, and with high death risk or risk of not finding another places suitable for colonization. This scale is usually the landscape scale (in the conservation integrated model) and the inhospitable area to be traversed refers to the landscape matrix, which can have different permeability patterns.
Geographic scale
Scale of great occurrence of the species, which usually is only experimented in its edges by the species that have elevated migratory capacities.

7.3. Levins' Model

7.3.1. Concepts and goals

- Colonization: Event in which individuals initiate a new population fragment in an empty habitat patch.
- Extinction (local): Event in which a patch becomes empty due to high emigration of individuals and high local death rate.
- Occupancy rate: It is the rate that represents the balance between colonization and extinction that affects the number of occupied patches in a determined metapopulation.
- Occupied patches: Number of patches occupied by local populations.
- Available patches: Represents the number of patches that are susceptible of colonization.

The main goals of the model are:

- Represent the most relevant aspects of the model proposed by Levins and its implications;
- Represent colonization and extinction turnover in relation to the occupation rate (occupancy).

7.3.2. Modeling approach

It is an advanced model because represents a basic mechanism and complex phenomena found in nature, that is not easily understandable. DynaLearn, when using its diagrammatical representation, Qualitative Reasoning machine and the possibility of simulation makes it easy to understand, for knowledge and concepts representation and to organize information.

7.3.3. Model ingredients

Table 7.5. Entities, quantities and quantitative spaces utilized in Levins' model.

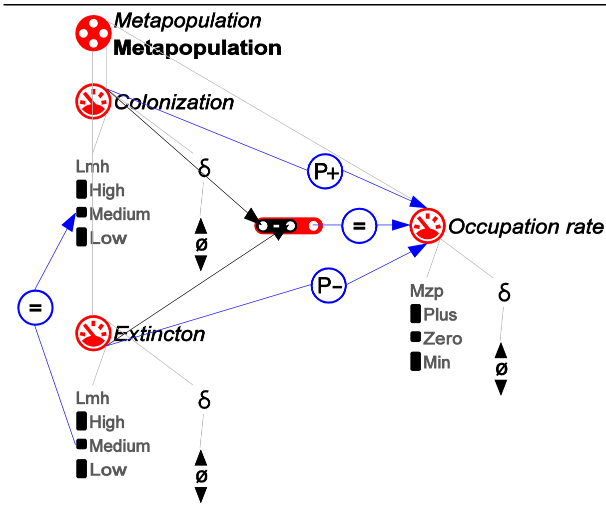
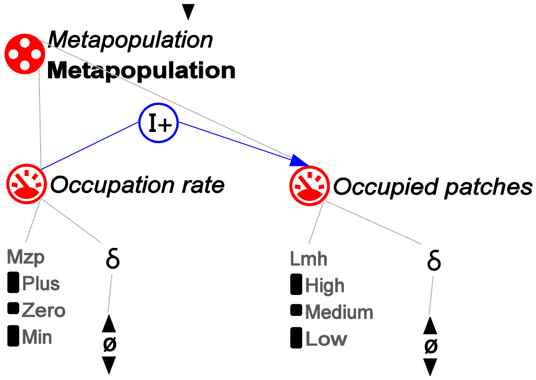
Entities	Quantities	Quantitative space
Metapopulation	Colonization	*{Low, medium, high}*
	Extinction (local)	*{Low, medium, high}*
	Occupancy rate	*{Min, Zero, plus}*
	Occupied patches	*{Low, medium, high}*
Habitat patch	Available patches	*{Low, medium, high}*

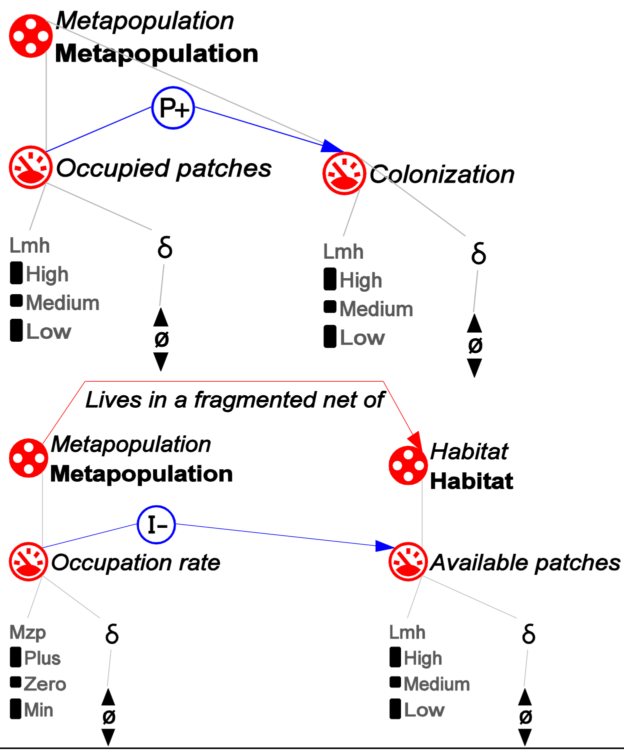
7.3.4. Model expression

7.3.4.1. Model fragments

The traditional Levins' model is constituted of 08 model fragments, of which 06 are static and have as role: describe the system's structure and show the indirect causality relations between the quantities [those represented by qualitative proportionalities (P+ and P-)]. The other two are fragments that represent the processes that are the primary cause of change in the metapopulational system: occupation of the available patches and the increase of number of occupied patches.

Table 7.6. Most relevant model fragments represented in the Traditional Levins' approach

Model fragments	Portion of the knowledge represented (conceptual domain)
	**Mf01 Colonization and extinction events** This model fragment represents the main idea of the original model proposed by Levins': the balance between the colonization and extinction rate that results in the occupation rate.
	**Mf02 Occupation process of habitat patches** The occupation rate represents the arrival of local populations in the habitat patches, what will increase the amount of occupied patches, which will determine the occupancy of the metapopulation.



Mf03 Relation between occupied patches and colonization
The colonization rate depends on the number of occupied patches. This causal relation is demonstrated in this model fragment by a P+ qualitative proportionality.

Mf04 The occupation of available patches
The occupation of the patches is also represented by a decrease of the available patches by an indirect influence (I-).

7.3.5. Scenarios and simulations

The models results come from the simulation of two main scenarios. Below follows the Figure (7.2) correspondent to scenario 02, in which the initial conditions are of high ‘colonization’ and medium ‘extinction’, having its value defined as exogenous variable (*random*). The exogenous variable *random* has a pre-defined behavior in which the derivative of these quantities will oscillate randomly. In the model, such behavior represents the colonization and extinction as stochastic effects inside of the metapopulation. It is an initial metapopulation and it is growing, because the ‘colonization’ surpasses the ‘extinction’ and the amount of ‘available patches’ is big, and of ‘occupied patches’ is low.

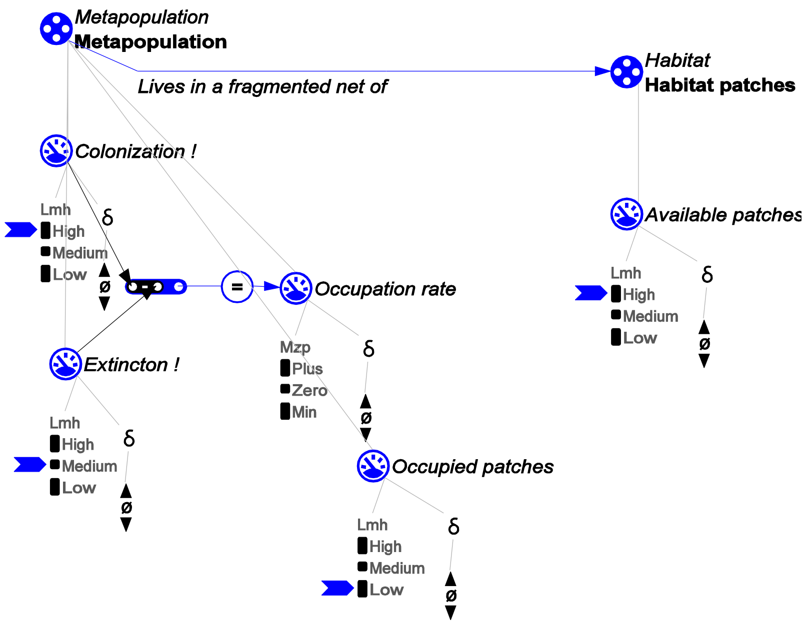


Figure 7.2. Scenario 02 'Influence of stochastic phenomena of extinction and colonization in a metapopulation growth.

Table 7.7. Simulation resume of scenario 02 'Stochastic extinction and colonization_growth of a metapopulation'.

Scenario name	**Scenario02 'Influence of stochastic phenomena of extinction and colonization in a metapopulation growth'**
Complete simulation	[53 states]
Initial states	[5]
Final states	[36, 38, 41, 42]
Relevant path	[1, 10, 11, 37, 38]
Behavior description	As expected, the quantities 'colonization' and 'extinction' reach a low stable value, at the end. 'Colonization' influences the number of 'Occupied patches' that reaches the maximum value and 'Available patches', this way, reach the minimum value. The positive 'Occupation rate' ends with 'zero' as value, since the maximum number of patches is occupied in a hypothetic situation of a metapopulation growing indefinitely, until the saturation of all 'Available patches'. In this situation, the variables have stochastic behavior, thus 'colonization' is bigger than 'extinction'. This way, the metapopulation kept on growing and occupying the 'available patches'.

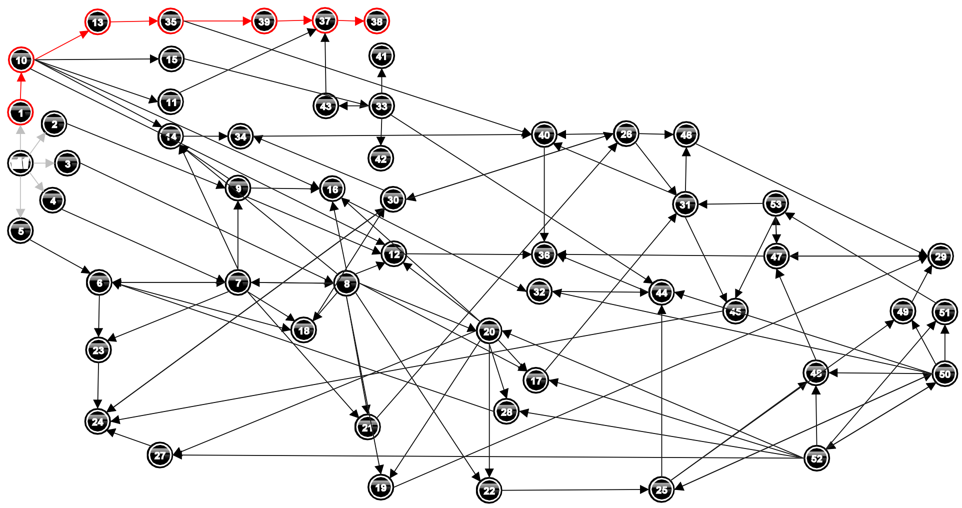


Figure 7.3. Behavior graph of a simulation initiated in Scenario02 ‘Influence of stochastic phenomena of extinction and colonization in a metapopulation growth’.

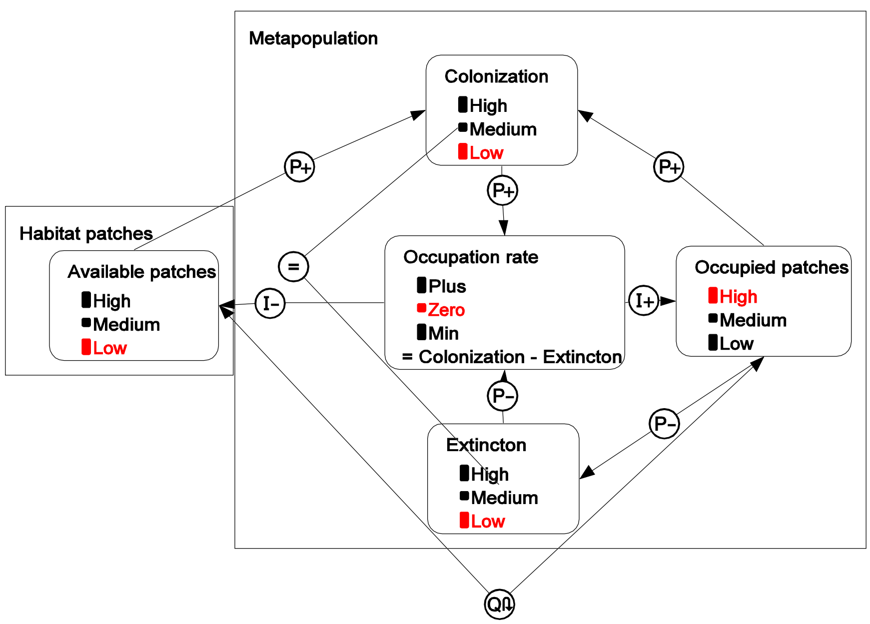


Figure 7.4. Causal model for the state [38] of the simulation of Scenario 02 ‘Influence of stochastic phenomena of extinction and colonization in a metapopulation growth’.

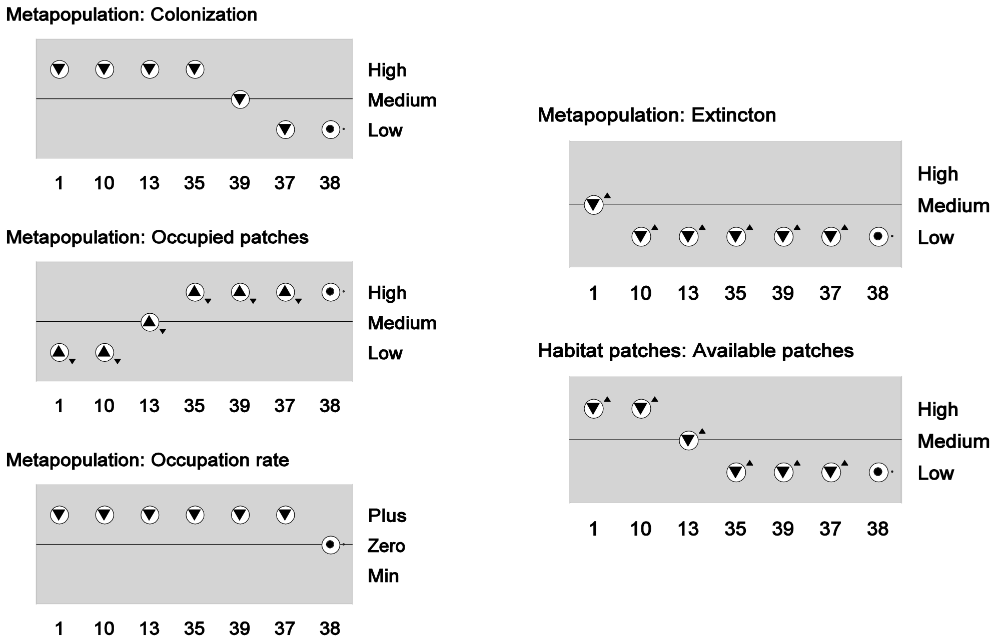


Figure 7.5. Value history diagram of selected quantities, obtained in the simulation of Scenario 02 'Influence of stochastics phenomena of extinction and colonization in a metapopulation growth'.

In Scenario 03 'Extinction decline of the metapopulation', the expected behavior is that the metapopulation has its occupancy decreased, since the local extinction rate is bigger than colonization. This scenario shows the following moment of a maximum occupancy, what results in a persistence cycle of the metapopulation, as idealized by Levins (1969). In Figure 7.6 it is possible to see the influences of the local extinction rate over the amount of available patches. Figures follow bellow:

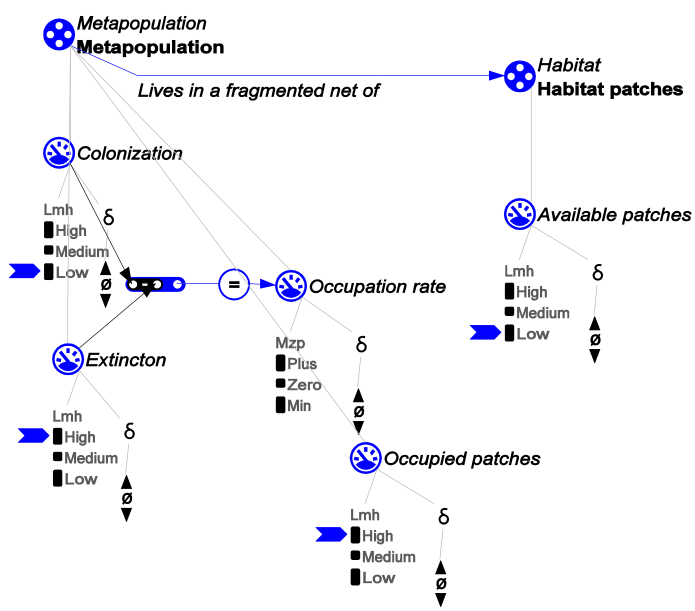


Figure 7.6. Scenario 03 'Extinction decline of the metapopulation'

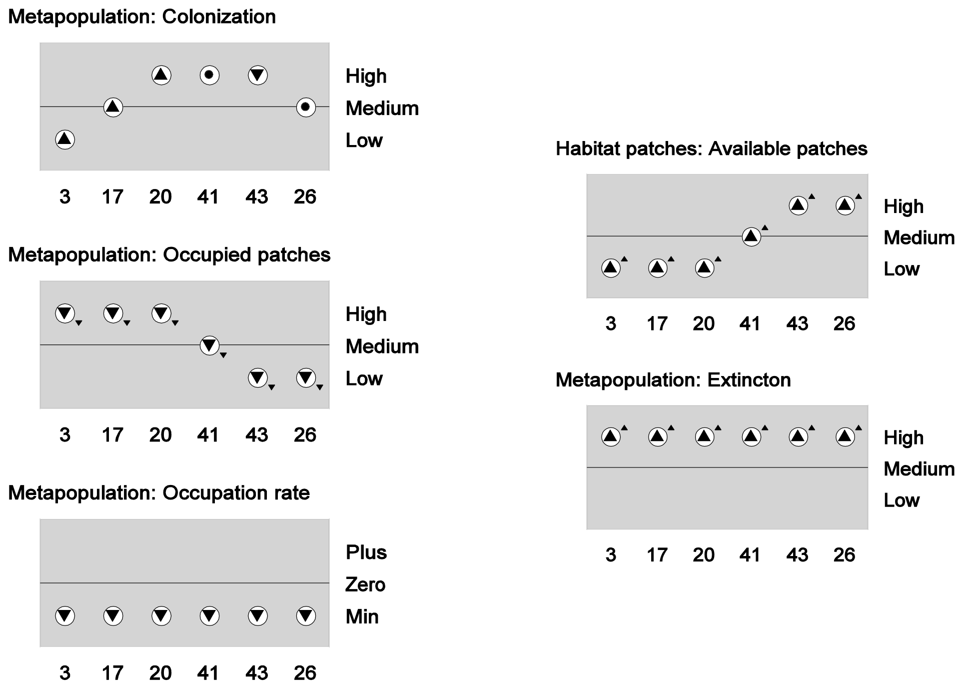


Figure 7.7. Value history diagram of quantities, obtained in the simulation of Scenario 03 ‘Extinction decline of the metapopulation’.

7.4. Source and Sink Model

7.4.1. Concepts and goals

- Source habitat is the place where the reproductive success is higher than death;
- Growth rate is the rate that represents the balance between birth and death and that influences the size of the population;
- Emigration rate represents the exit of individuals of the source habitat, which are result of the excess, produced by high local reproduction: birth is higher than death;
- Sink habitat is the place where the reproductive activity is smaller than death;
- Immigration rate represents the entrance of individuals in the sink habitat, which are from the source habitat. In the sink habitat, the local reproduction is not enough to replace the loss of dead individuals;
- Propagules: Individuals in traffic, emigrating to a new habitat.

The main objectives of this model are:

- To investigate the interactions between two local populations that can behave as “source and sink”;
- To represent a model formed by two subpopulations that interact by means of dispersion and that inhabit, one of them in “source” habitat, and the other, “sink”;

- To show how birth, death, and dispersion (emigration and immigration) affect the persistence of a metapopulation;
- To show how density dependent relations affect the movement of individuals from source to sink, accordingly to Pulliam's proposal (1988), revised by Kawecki (2004) and Hanski (2004).

7.4.2. Modeling approach

It is an advanced model because represents a basic mechanism and complex phenomena found in nature, that is not easily understandable. DynaLearn, when using its diagrammatical representation, Qualitative Reasoning machine and the possibility of simulation makes it easy to understand, for knowledge and concepts representation and to organize information.

7.4.3. Model ingredients

The structure of the "source and sink" metapopulation is represented by three entities: 'Habitat', that refers to the physical place and that represents a habitat patch, which gathers the necessary local environmental conditions to the survival of the local population (Kawecki, 2004); a "Local population" and "Landscape matrix", which was not represented in the original models proposed by Pulliam (1988; 1996). The matrix was added, in this model, and represents the places where the propagules that are in dispersion are found. The matrix and its characteristics, as type and permeability, can make a lot of difference, in the sense of altering the individual flux speed, facilitating or making difficult the emigration/immigrations process (Hanski, 2008).

Entities of the model and the configurations between them:

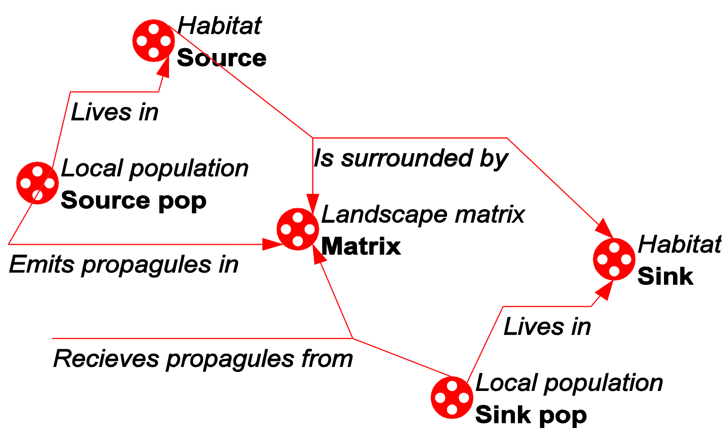


Figure 7.8. Entities of the model 'Source and Sink'.

The source and sink model has 07 quantities, with 05 different quantitative spaces. The Table below relates entities and quantities and their meaning in the model.

Table 7.8. Entities, quantities and quantitative spaces utilized in the Source and Sink model

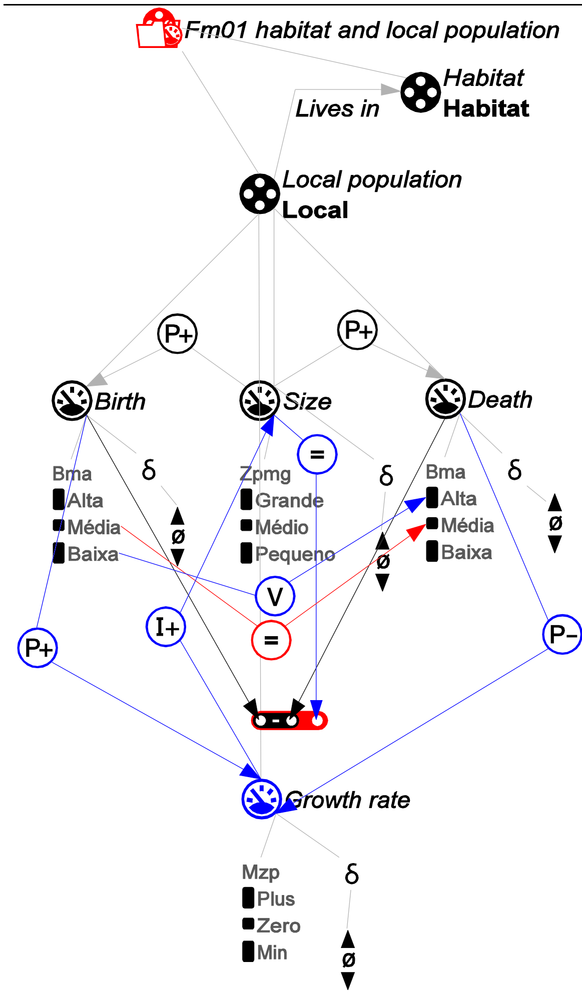
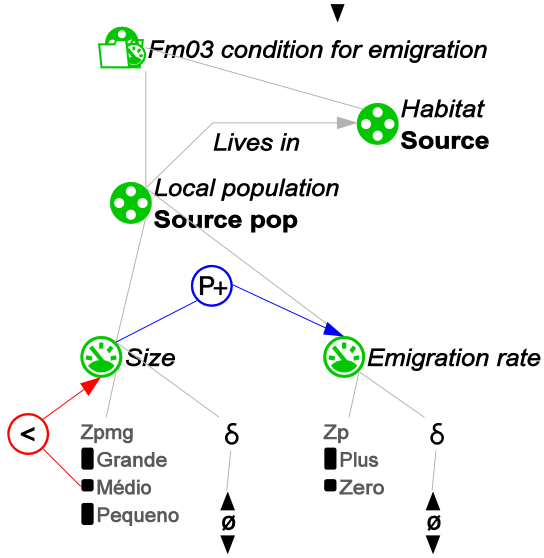
Entities	Quantities	Quantitative spaces
Local population (Source habitat)	Birth	*{High, medium, low}*
	Death	*{High, medium, low}*
	Growth rate	*{Min, Zero, plus}*
	Size	*{Zero, small, medium, large}*
	Emigration rate	*{Zero, plus}*
Local population (Sink habitat)	Immigration rate	*{Zero, plus}*
Landscape matrix	Propagules	*{Plus}*

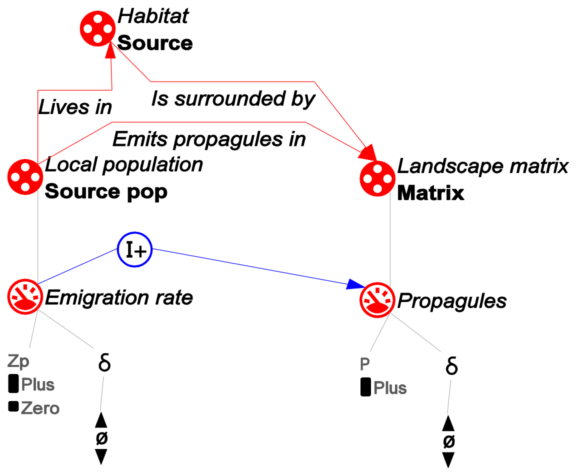
7.4.4. Model expression

7.4.4.1. Model fragments

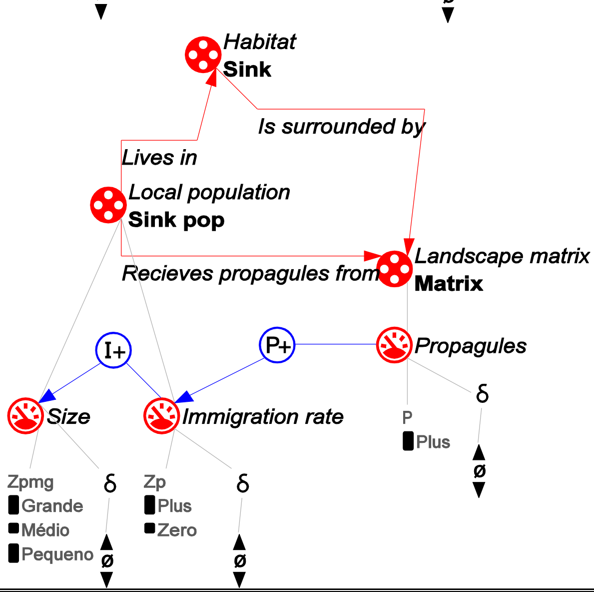
The qualitative model 'Source and Sink' is made of 10 model fragments, of which 07 are static ones. The other three are fragments that represent the processes: growth of the local population, emigration of the source habitat and immigration to the sink patch. Note that the conditions are modeled using the aid of colors, in DynaLearn. Thus, the expressions in red represent 'conditions' (if…) and the expressions in blue represent the 'consequences' (then…). For example: If the 'Size' of a local population is smaller of equal to the 'medium' value, then the derivative of the "Emigration rate' will be equal to 'zero' (see Figure, below, of the Mf03a condition to emigration_local size smaller than medium).

Table 7.9. Most relevant model fragments represented in the model ‘Source and Sink’

Model fragments	Portion of knowledge represented (conceptual domain)
	**Mf02 Vital rates in local population** This fragment gathers the main relations that exist in the local population that lives in a determined habitat patch. Those are: the influence of ‘Birth’ and ‘Death’, respectively ‘positive’ (P+) and ‘negative’ (P-), over the ‘Growth rate’ of the population. The balance of those two variables results in the ‘Size’ of the local population. In this relation, there is a positive feedback loop, coming from the quantity ‘Size’ to the variables: ‘Birth’ and ‘Death’. This feedback mechanism represents a density dependent relation: the bigger the local population size, the bigger death and birth. The ‘Growth rate’ influences directly (I+) the ‘Size’ of the local population.
	**Mf03a Conditions to emigration_local size bigger than medium** When the size of the ‘local population’ is bigger than ‘medium’, the local population becomes ‘Source’, what is propitiated by the local conditions offered by the habitat (Pulliam, 1988). In Mf03a, this condition is expressed in red, and has as a consequence the activation of the indirect and positive influence (P+) of the ‘Size’ over the ‘Emigration rate’.



Mf04 Emigrations of individuals of the source habitat
This fragment represents the following process: the 'Emigration rate' exercises a positive direct influence (I+) over the state variable 'Propagules' in the landscape matrix. The individuals in 'excess' will migrate in search of a new habitat, the sink (Pulliam and Danielson, 1991).



Mf05 Immigration of individuals in the sink habitat
The entrance of individuals in the sink population depends on the influence of the 'Propagules' present in the matrix, what is represented by the positive indirect influence (P+) over the 'Immigration rate'. The immigration of individuals will increase the 'Size' of the local population ('Immigration rate' is a positive direct influence [I+] over the 'Size').

7.4.5. Scenarios and simulations

The results of the model come from the simulation of the main two scenarios. Below follows the Figure correspondent to the scenario 'Sce03 Source population has growth rate higher than of the sink', in which the initial conditions are of high 'Birth' and medium 'Death'. The 'Size' of the local population is small and crescent, so there is still no exceeding population of individuals to the emigration and the 'Emigration rate' stays stable, equal to zero. In the population that lives in the sink habitat, the value of 'Birth', 'Death' and 'Size' are medium. The 'Immigration rate' is equal to zero. From these initial values, the simulation is made, and below follow the resume and the correspondent figures:

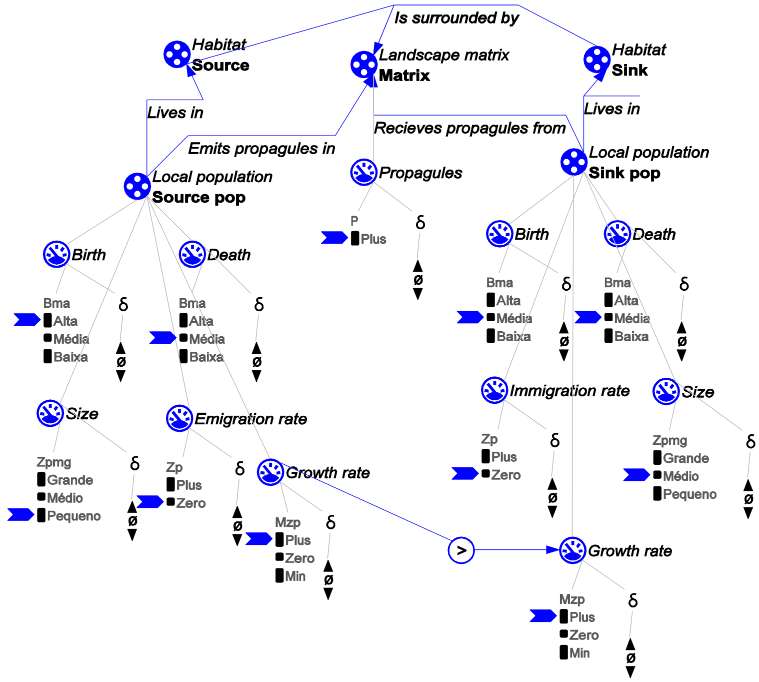


Figure 7.9. ‘Sce03 Source population has growth rate higher than of the sink’

Table 7.10. Simulation resume of Sce03 Source population has growth rate higher than of the sink

Scenario name	**‘Sce03 Source population has growth rate higher than of the sink’**
Complete simulation	[97 states]
Initial states	[9]
Final states	[60, 63, 65, 68, 71, 73, 77, 83, 88, 89, 90, 93, 94]
Relevant path	[1, 18, 19, 45, 46, 79, 85, 94]
Behavior description	As signalized in the initial scenario, the ‘growth rate’ of the local population of the source habitat is higher than the one of the sink. In this circumstance, according to the value history diagram of the Figure 7.12, below, from the state 19, it is possible to note that the ‘Size’ of the source population increases and so influences the growth of the ‘Emigration rate’. By consequence, there is the increase of the vital rates and of the ‘Size’ of the sink habitat population, which now absorbs the propagules that were sent. It is also noted that the ‘Growth rate’ of the sink population has the value ‘min’ (minus) in the last state, in other words, it is negative, meaning that this population is identified as a real sink population (Pulliam and Danielson, 1991), that cannot withstand the local population without the entrance of individuals via immigration. In the causal model below, in Figure 7.11, it is possible to identify the difference in the relations when the source population has a small ‘Size’, because the last does not influence the ‘Emigration rate’ in state 01. In state 794, it is possible to note that the ‘Size’ is big, thus, there is the presence of positive qualitative proportionality [P+] over the ‘Emigration rate’.

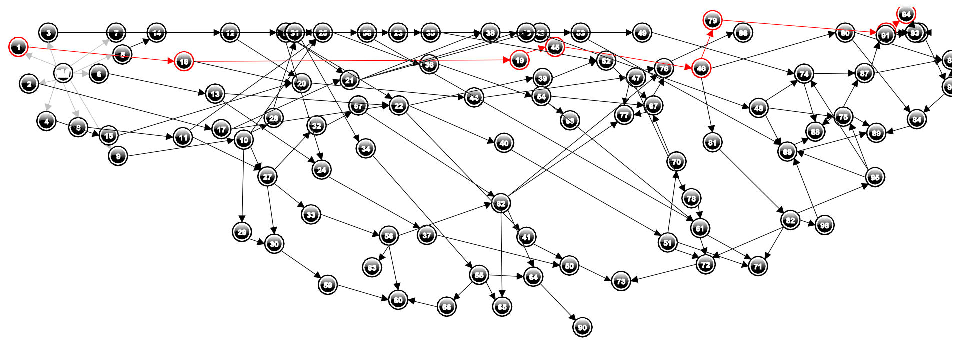


Figure 7.10. Behavior graph of the simulation initiated in scenario 03 'Sce03 Source population has growth rate higher than of the sink'.

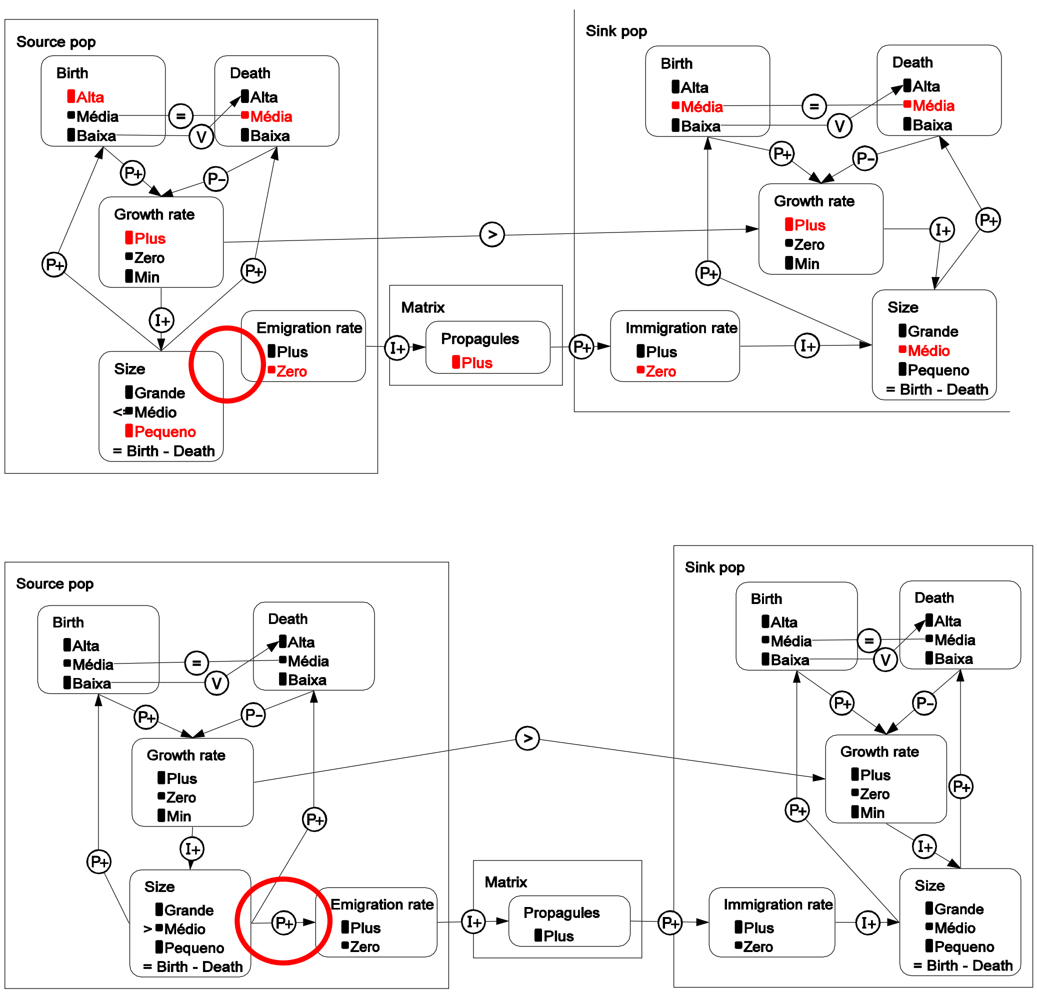


Figure 7.11. Causal model of the states [01] without the influence of 'Size' of the source population over the 'Emigration rate' and the state [79], in which the influence is already present, because the size of the source population, in this state, is big. They were obtained of the simulation of the scenario 'Sce03 Source population has growth rate higher than of the sink'.

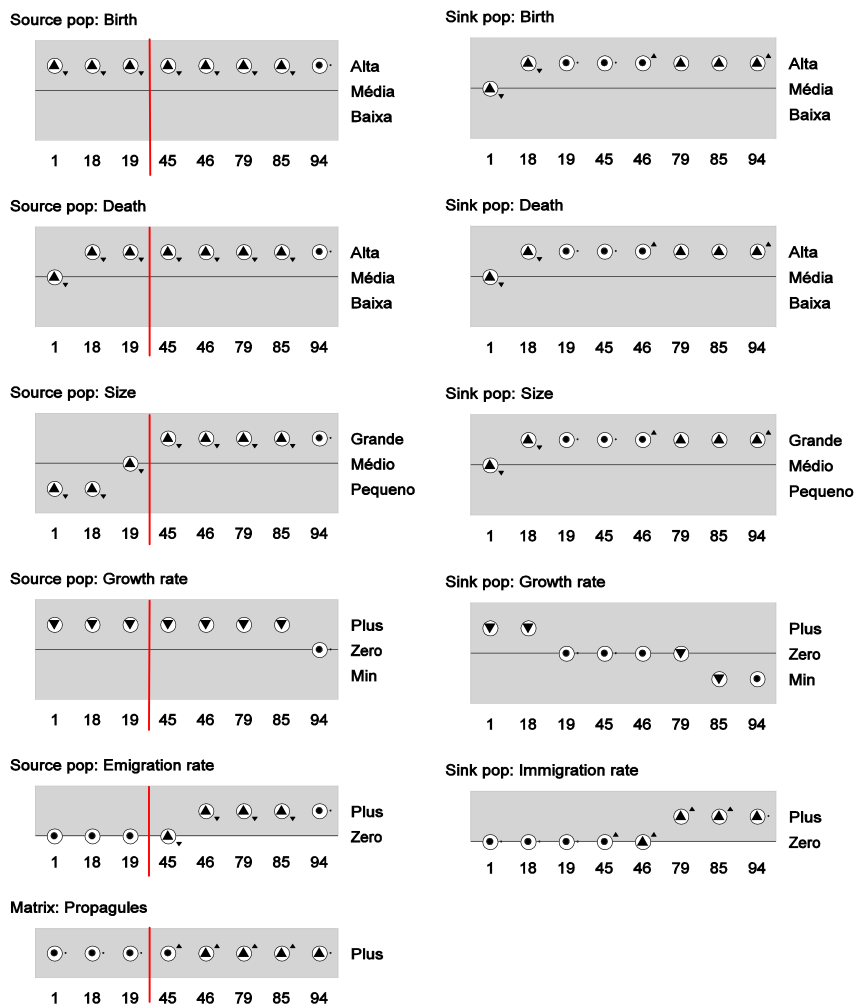


Figure 7.12. Value history diagram of the quantities obtained in the simulation of the scenario 'Sce03 Source population has growth rate higher than of the sink'. The change of behavior, with the movement of the individuals from source to sink, occurs from state 19 onwards.

In scenario 03b 'Source population has a positive emigration rate' (Figure 7.13), the expected behavior is that the condition for the existence of the source population is attended: the 'Emigration rate' is always positive. The simulation shows the oscillation of the 'Growth rate' in the sink population, which is influenced by the 'Immigration rate'. From state 17 (Figure 7.14, value diagram, below), it is noted that the derivative of the 'Immigration rate' is positive and crescent. It is said to be crescent because of the second order derivative represent by the small sign (Δ) in the superior right corner, aside of the value of the derivative in states 17 and 25, that come first of the moment in which the 'growth rate' of the sink population goes from 'zero' to 'positive', again. Such behavior is expected for real sink subpopulations (Nee, 2007)

The status of the source or sink habitat has no direct relation with the size of the local population. Sink can be filled, while sources can be small. The difference is the reproductive quality of each one (Pulliam, 1988). That is why the qualitative model is useful to compare populations with different carrying capacity, because the size is relative, it is a qualitative value. The *per capita* production of individuals is what needs to be bigger in the source, so that it can withstand the sinks.

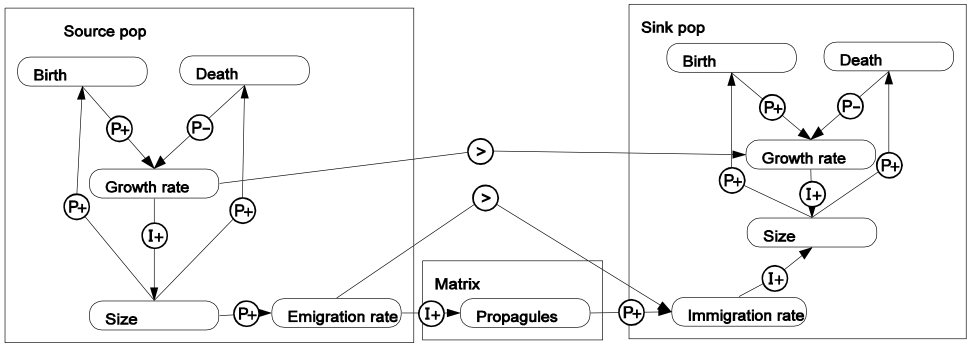


Figure 13. Causal model obtained in a simulation starting with the scenario 03b ‘Source population has positive emigration rate’.

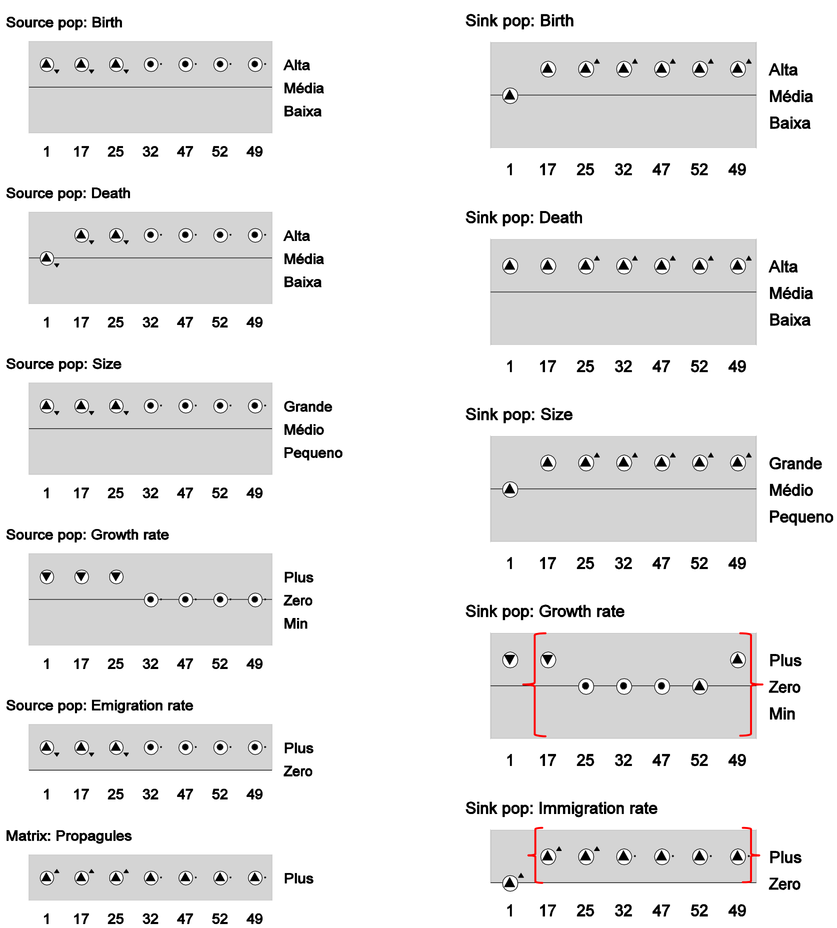


Figure 7.14. Value history diagram of the quantities in the simulation of the scenario 03b ‘Source population has positive emigration rate’.

Different types of habitat can be recognized from the information about the growth rate and about the local population size (Pulliam and Danielson, 1991). The Figure 7.15 illustrates how the sum of the two different habitats produces a metapopulation with a bigger individual number than the stock of the source habitat and of the sink.

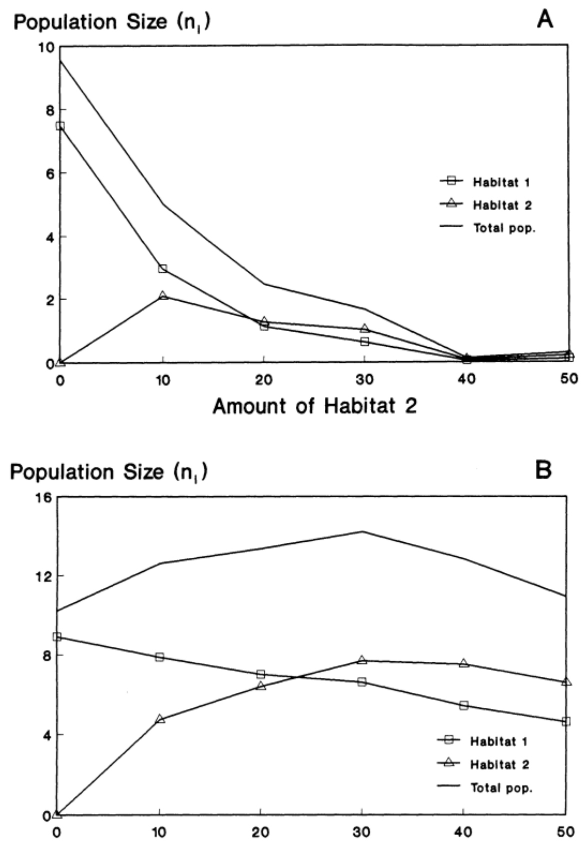


Figure 7.15. The total size of the metapopulation is resultant of the sum of two populations: one that lives in a higher quality habitat and other, in a lower quality one. The proportion of the local population that reproduces in the higher quality habitat is given in function of the total of the two types of habitat and also the selective ability of the species (Adapted from Pulliam and Danielson, 1991).

The theme in discussion can sound very simple: one local population produces an individual excess, which serves to feed another population, in decline. However, have the members of a given population the capacity of discriminate habitats of different qualities, and even note subtle differences between the patterns of death and reproduction? (Murphy, 2001) That is why the better understanding of the selective ability of species in relation to the different types of habitats is also object of investigation (Stamps, 2008).

Examples of species that organize themselves in the structure of source and sink habitats (Pulliam and Danielson, 1991): Meadow Mouse (*Microtus pennysilvanicus*), squirrels

(*Tamiasciurus* spp.), Deer Mouse (*Peromyscus maniculatus*) and the Reindeer (*Rangifer tarandus*). There are also cases of some plants, such as the species *Cakile edentula*, that lives in sand dunes. The ones that live in the side of the sea are in a source habitat, where the greater part of the seeds is produced. The sink habitat lies near the dunes' crests, where the seeds that are transported by the wind fall (Kawecki, 2004).

The recognition of the existence of source and sink populations is essential to raise important questions such: in what type of habitat the bigger part of individuals in a metapopulation lives? Is there the possibility of the sink habitats to be removed without threatening the persistence of the metapopulation? Answer such questions requires the better understanding of the mechanisms involved in the dynamic if the type 'source and sink', which has important clues to the conservation and handling of metapopulations (Pulliam and Danielson, 1991).

It is in this sense that the previous theoretical investigation is important, before the search of empirical evidences. This investigation can be a step developed with the aid of qualitative models. To answer questions such: what kind of data need to be collected to investigate if in a determined are has habitats of the type source and sink? With the aid of the model, it is possible to understand that, without information about the vital rates of the local populations and also about the emissions of propagules, there is no way to recognize such patterns in nature.

7.5. Conservation Integrated Model

7.5.1. Concepts and goals

This qualitative model was created having basis in the ideas of Ilkka Hanski (1982 – 2008) and also has important theoretical elements of landscape ecology and conservation biology. The objective of the model is communicate a synthesis of the main theoretical elements present at the metapopulation models published by Hanski (2008), and that involve relevant aspects that, until then, had not been addressed by many ecologists. It is important to highlight that the qualitative models represent the dynamic of the metapopulations in a continuous period of time, not dealing with the notion of probability which the discrete time models refers to.

Main questions to be answered by the model

- Which are the main variables that affect the metapopulation dynamics in a local scale?
- Which are the main variables that affect the metapopulation dynamics in a regional scale?

- Which are the exogenous factors that affect the metapopulation dynamic and which are its effects over the balance of extinctions – colonizations?
- Is it possible to aggregate elements of exogenous influence (human influence, human activities and changes in soil use) to other intrinsic influences, to show its effect on metapopulations?

The main objectives of the model are:

- To represent characteristics of habitat patches (in local scale) that influence local population dynamics (carrying capacity, size and quality).
- To represent the main characteristics of a local population (vital and migratory rates) that affect local dynamics of metapopulation.
- To represent the different influences, combined and isolated, of variables that influence the habitat and local population, and, that affect the colonization and extinction rate.
- To represent the added effect of different variables that act synergistically, to prevent the extinction of local populations in a regional scale.
- To represent the effect of the environmental and demographical stochasticity added to the deterministic events, to show their influence over metapopulations.

7.5.2. Modeling approach

It is an advanced model because represents a basic mechanism and complex phenomena found in nature, intending to be an advance in metapopulation theory. It is also advanced because, besides the extensive use of conditional knowledge, it explores the notion of scales, combining, in the same model, two scales, regional and local, and presenting a modeling solution for the problem of how to model it.

7.5.3. Model ingredients

The structure of the metapopulation represented in 'integrated model' consists of five entities: the 'Habitat', that refers to the physical place and that 'has' the 'Set of patches', that 'has' the local patch. While the 'Set of patches' houses the 'Metapopulation' (set of local populations', the 'Local patch' *restrains* only the 'Local population', which refers to the individuals subgroup that eventually disperses to other local groups.

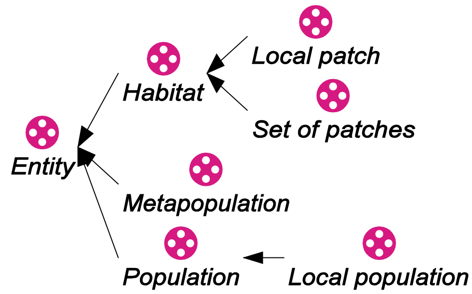


Figure 7.16. Entities of the 'integrated conservation' model.

The main model agents follow below.

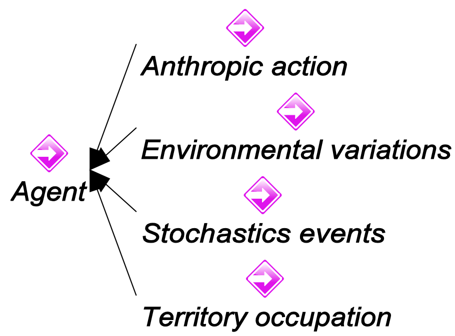


Figure 7.17. Agents of the integrated conservation model.

The integrated model has 21 quantities, with 07 different quantitative spaces. The Table below relates the entities and quantities and presents their meaning in the model.

Table 7.11. Entities, quantities and quantitative spaces utilized in the integrated model - processes

Entities	Quantities	Quantitative space	Observations
Local population (Populational subunit that constitutes the metapopulation)	Birth rate	*{Zero, plus}*	Number of individuals born per time unit
	Death rate	*{Zero, plus}*	Number of death per time unit
	Growth rate	*{Min, Zero, plus}*	It is the rate that influences the size of the population. Is affected by natality (birth of individuals) and mortality processes (death of individuals), as well as by emigration and immigration
	Immigration rate	*{Zero, plus}*	Individuals entering the local population, coming from another patch
	Emigration rate	*{Zero, plus}*	Individuals leaving the local population
Metapopulation (defined as a set of local populations)	Colonization rate	*{Zero, plus}*	Represented by the rate in which the individuals start a new population fragment in an active empty local patch
	Extinction rate	*{Zero, plus}*	The rate at which local extinction process occur, which depends of the quality and connectivity of the patches, among other factors.
	Variation rate	*{Min, zero, plus}*	Determines the behavior of the metapopulation, making it be crescent, stable, declining.

Table 7.11a. Entities, quantities and quantitative spaces utilized in the integrated model.

Entities	Quantities	Quantitative space	Observations
State variables (entities properties)			
Set of patches (Aggregates, in local scale, the local habitat patches that contain local populations)	Total area	*{small, medium, big}*	Resultant area of the sum of the amount of habitat patches existent in the landscape
	Quality	*{good, medium, bad}*	It is a qualitative measure of the conservation state of the patches that house the metapopulation
	Connectivity	*{good, medium, bad}*	The connectivity is a qualitative evaluation of the proximity between the habitat patches
	Empty patches	*{zero, small, medium, big, maximum}*	Patches which are suitable, but they are still empty: local population was extinct or the patch was not colonized yet.
	Occupied patches	*{zero, small, medium, big, maximum}*	Patches that are suitable and that are occupied
Local patch (Non-linear homogeneous habitat area, of the landscape, that distinguishes itself from the neighbors and can house the local population)	Quality	*{zero, low, medium, high}*	It is a qualitative measure of the resources available and represents the characteristics that enhance the fitness of the local population
	Carrying capacity	*{zero, low, critic, high}*	The size of the population that can be theoretically sustained by a habitat patch under specific conditions (Cioaca *et al*, 2009).
	Adequate size	*{small, medium, big}*	It is the qualitative measure of the average size of the suitable area of preference of a given species
Local population	Number of individuals	*{zero, small, medium, big}*	Amount of individuals that composes the local population and that is influenced by the growth rate
Environmental variations (agent)	Environmental variation	*{positive}*	Indicates the existence of exogenous coming from the surroundings environments, that affect indirectly the quality of habitat patches
Local and regional stochastic events (agent)	Stochastic events	*{positive}*	Indicates the existence of exogenous influence, coming from events like fire, floods, clearings, and other, that can affect the local patch quality and of the set of patches in regional scale
Territory occupance (agent)	Soil use	*{positive}*	Exogenous influence that has as origin the human activities that involve the use of the soil for different ends (such as the agricultural and cattle activities)
Anthropic action (agent)	Damages in corridors	*{positive}*	It is the intense process of the alteration of the natural landscape, that destroys habitat patches and dispersion corridors and alters the connectivity between patches

Assumptions in qualitative models are conditions established to define alternate situations, and to signalize which model fragments are selected by the reasoning engine, during the simulation of a given scenario. It is like a marker that the inference machine of the Garp3 software identifies when selecting model fragments. In this model, the following assumptions were utilized to separate different time and space scales:

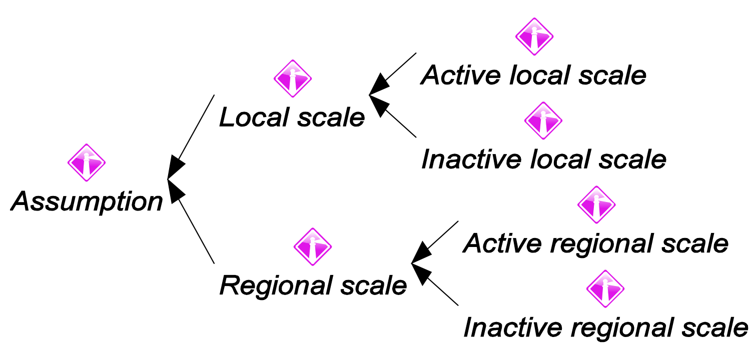


Figure 7.18. Assumptions of the integrated model

In those conditions, depending on the assumptions present in the scenario (for example, 'Active regional scale' and 'Inactive local scale'), only the model fragments that have the same assumption will be selected to the simulation.

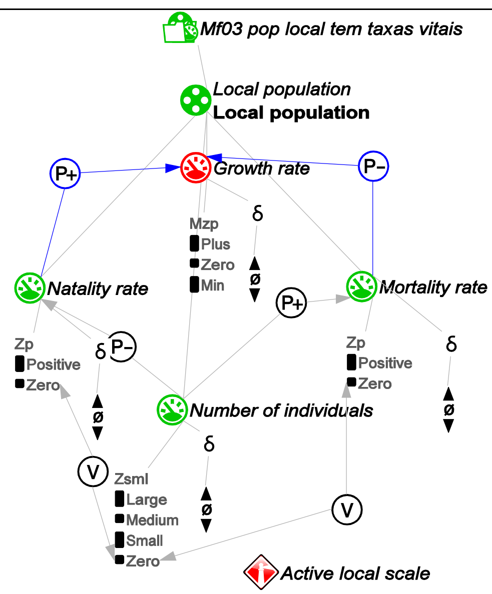
7.5.4. Model expression

7.5.4.1. Model fragments

The 'integrated' model is constituted by 60 model fragments, of which 42 are static, 03 are processes and 15 are agents (exogenous influence). The processes are: growth of the local population, the balance variation between occupied and empty patches in the regional scale and the turnover between colonization and extinction, and their effect on the local scale. Bellow follows the most relevant fragments:

Table 7.12. Most relevant model fragments represented in the conservation integrated model.

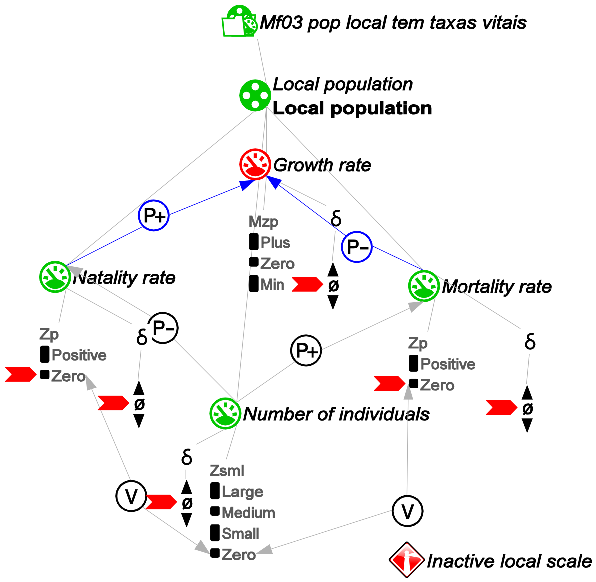
Model fragment



Mf03a Vital rates in local population active local scale

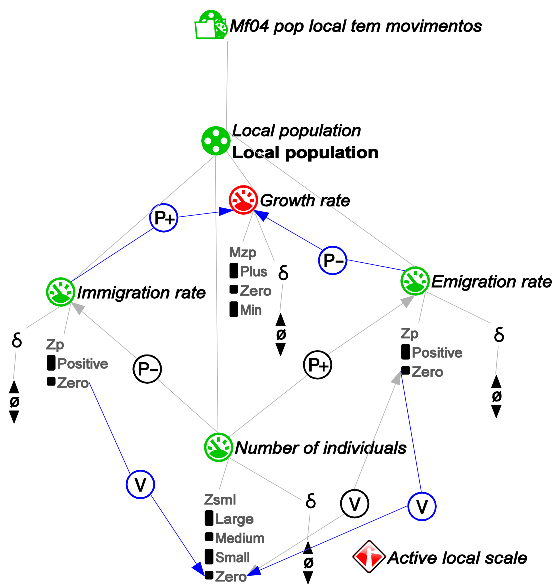
The influences in the birth rate (positive) and death rate (negative) over the growth rate of the population are represented. The density dependent relations are represented by the indirect influence (proportionalities), which go from the number of individuals to the birth rate (P-). The bigger the individuals' number, the smaller birth will be; and to the death rate

(P+): the bigger the number of individuals, the bigger death rate will be.



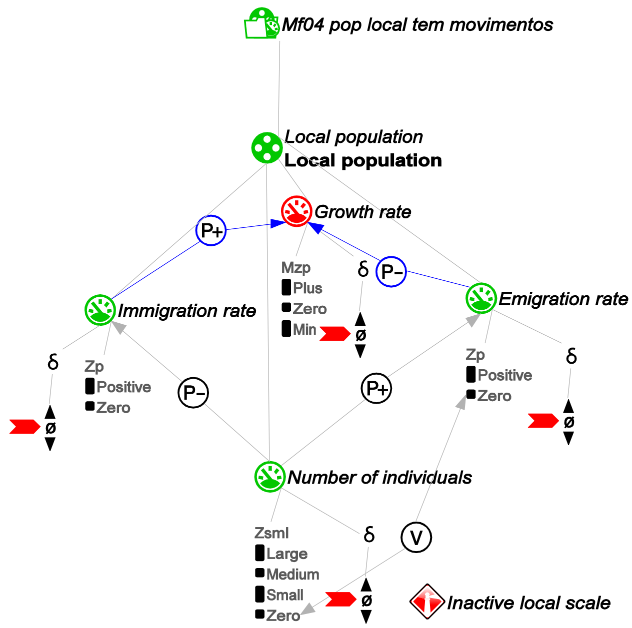
Mf03bVital rates in local population inactive local scale

Represents the same idea of the previous fragment, but now the local scale is inactive (there is the presence of assumption 'Inactive local scale'). So, the derivatives of all the quantities are equal to zero.



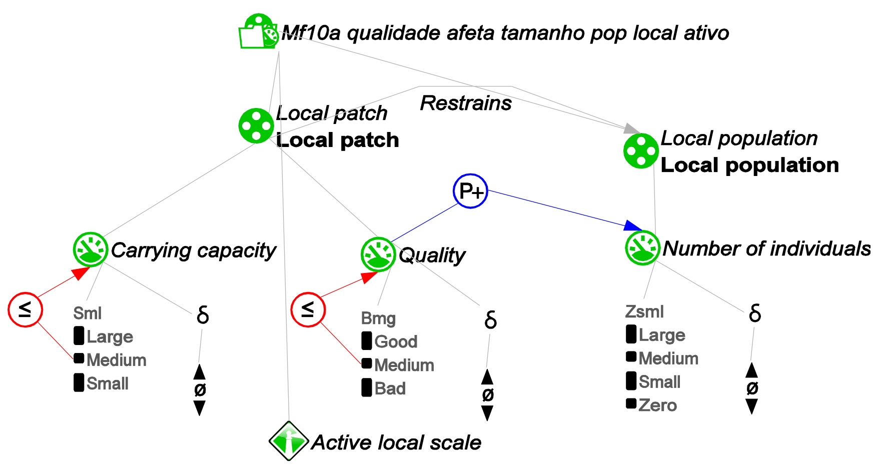
Mf04a Local population has movement active local scale

This fragment represents the influence of the emigration (negative) and immigration (positive) rates over the local population growth rate. Such rates receive *feedback* from the size of the population: the bigger the population, the smaller the immigration and the bigger the population, the bigger the emigration. If the population is smaller, the inverse is applied. There is an assumption that indicates that in this fragment there is the presence of the conditions to the local scale to be active in the simulation.



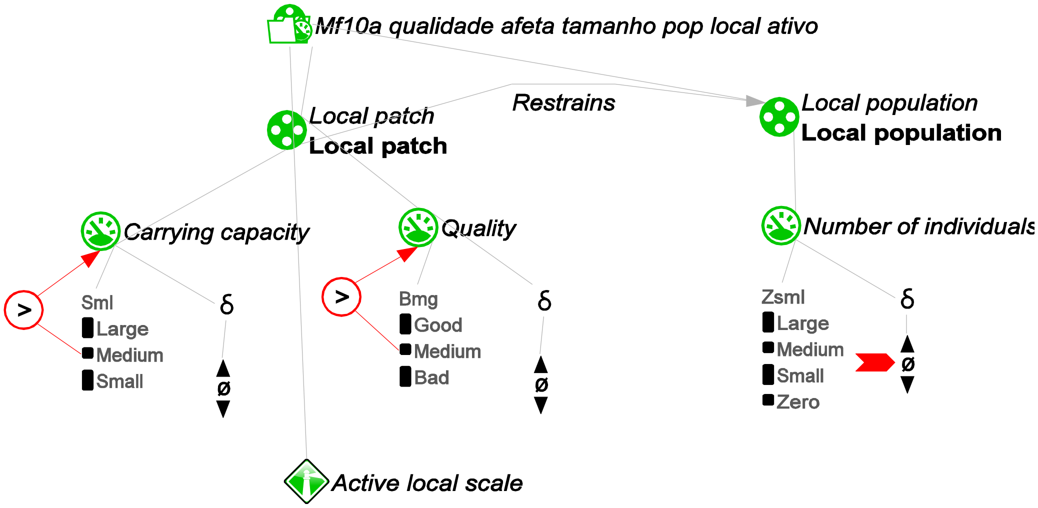
Mf04b Population has movement inactive local scale

Represents the same idea of the previous fragment, but now the local scale is inactive (there is the presence of the assumption 'Inactive local scale'). So, the derivatives of all quantities are equal to zero.



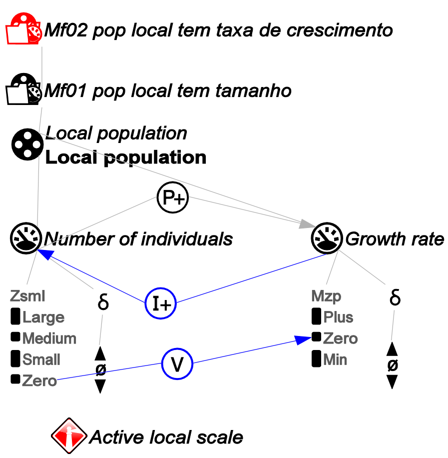
Mf10aa The carrying capacity and the local patch quality also affect the size of the local population

It is represented, via conditional knowledge, that if the 'carrying capacity' and the 'quality' of the patch have qualitative values higher or equal to 'medium', then quality will positively influence the number of individuals. If the quality of the patch is higher, then the number of individuals of the local population increases.



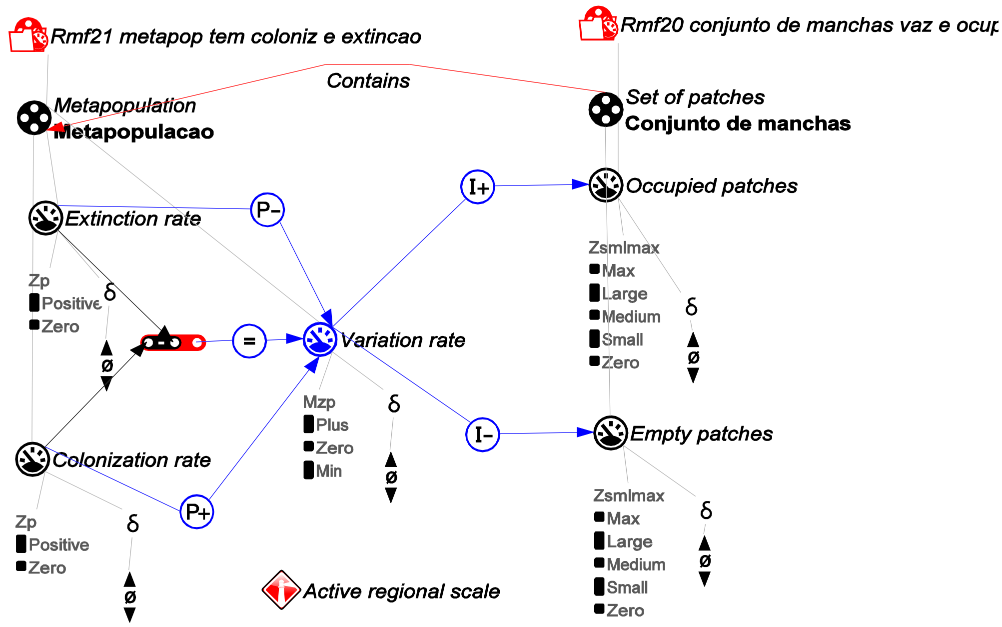
Mf10ab The carrying capacity and the local patch quality also affect the size of the local population

It is represented, via conditional knowledge, which if the 'carrying capacity' and the 'quality' of the patch have qualitative values smaller than 'medium', then quality will not influence the number of individuals.



Fm05 Local population growth_active local scale

This fragment represents the growth process: The growth rate directly influences (I+) the number of individuals in the local population. There is a positive *feedback* of the number of individuals to the growth rate, what means that the bigger the individuals number, the growth rate will receive influence, in order to grow.



Rmf22a Metapopulation variation is balance of the combined action of colonization and extinction

The difference between the extinction rates (negative influence) and colonization rates (positive influence) are used to calculate the metapopulation variation rate. If the variation is positive, the number of occupied patches increases (and simultaneously the empty patches decreases); if it is negative, the empty patches increase, as consequence of the extinction of local patches. The dependency that goes from the occupied patches to the extinction rate represents the 'rescue effect' (Hanski, 1991). The amount of occupied patches has correlation with risk of extinction, so the negative indirect influence is adequate to represent such relation.

7.5.5. Scenarios and simulations

The two scenarios that represent the 'Local and regional processes of a metapopulation' have the metapopulation perspective as a whole: the set of patches is affected by the extinction and colonization processes; and in other inferior time and space scale, it is the content of each one of the patches: a local population, with is characteristics. The diagrammatic representation, by means of QR models, is simple, but allows the clearly visualization of which are the processes that are affected in different scales: local and regional.

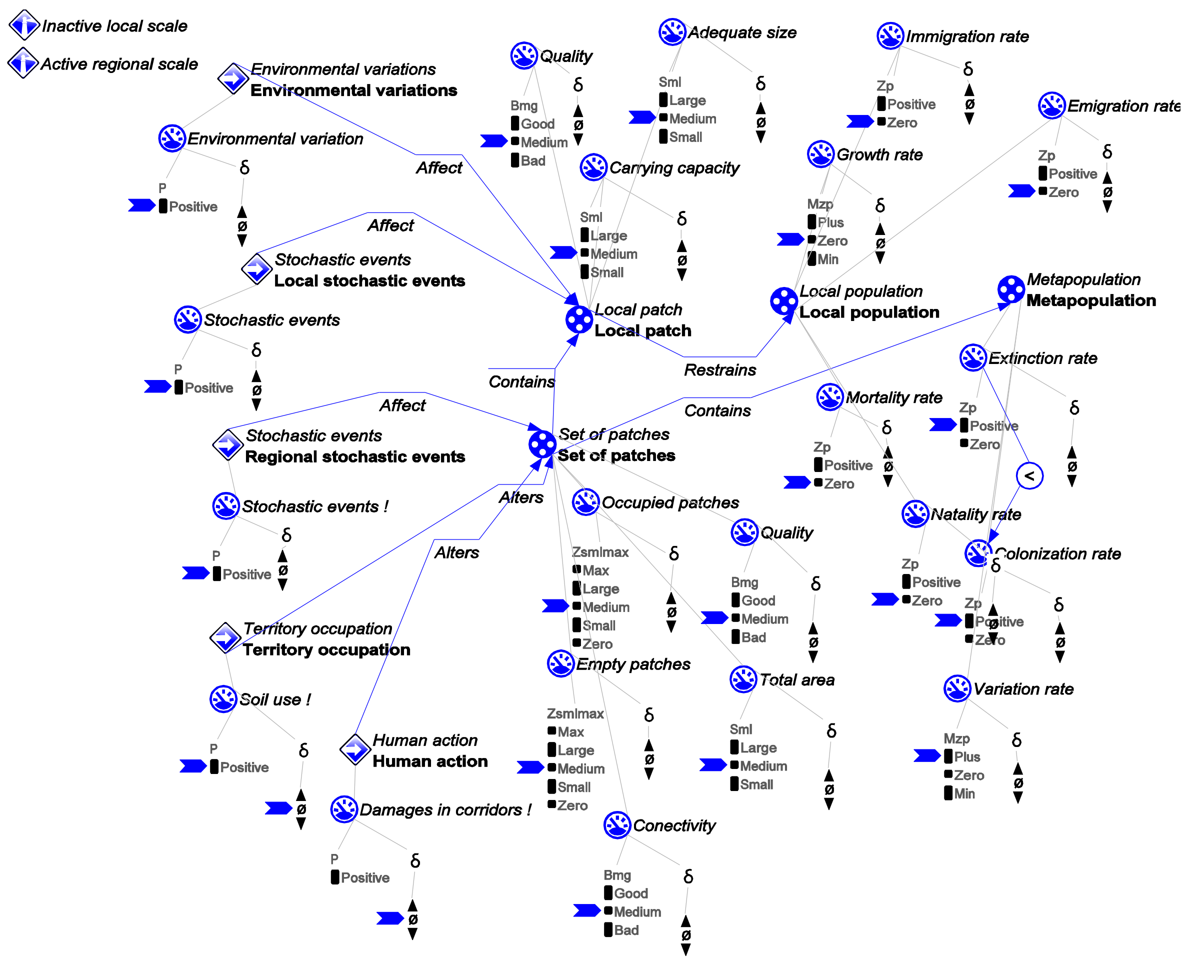


Figure 7.19. Scenario Tsce01a Active regional processes local inactive

Table 7.13. Resume of the scenario simulation

Scenario name	**Tsce01a Active regional processes, local inacive**
Complete simulation	[4 states]
Initial states	[1]
Final states	[4]
Relevant path	[1, 2, 3,4]
Behaviour descripition	According to the values of the initial scenario, the represented metapopulation has a 'small' number of occupied patches and a 'big' number of empty ones. It is affected by exogenous variables: stochastic events, soil use and anthropic actions. The set of patches initially presents medium quality, total areal and connectivity. The colonization rate is higher than the extinction rate, and the metapopulation variation rate is positive. The rates attributed to the local population have value equal to zero because are inactive in the regional scale (it is not possible to see its variations using this frame). The simulation had as a

result: the environmental variation, damages to corridors and the soil use are stable and positive through time. The stochastic events have a decreasing behavior, but positive. The set of patches persists with total area, medium carrying capacity and connectivity, and this situation allows that the quality increases. The set of occupied patches increases and the empty ones decreases, because the colonization is bigger than the extinction rate (see value history diagram in Figure 39).

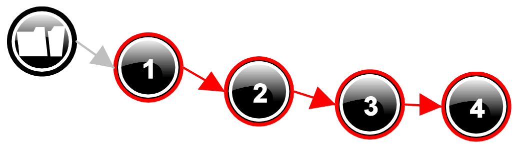


Figure 7.20. Behavior graph of the simulation initiated in the scenario Tscen01 active regional processes locals inactive.

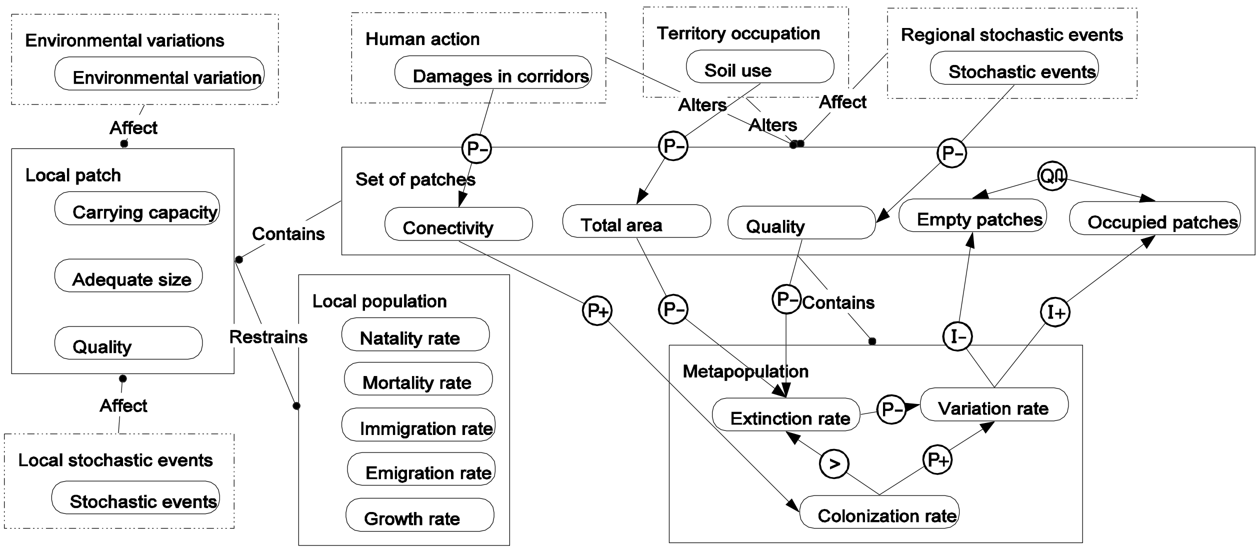


Figure 7.21. Causal model of the state [04], with the main relations that affect the local and regional population dynamic, being only the regional active (scenario Tcen01a active regional processes, local inactive). Highlight to the quantities that affect the extinction rate (connectivity, total area, quality and occupied patches) and the colonization rate (connectivity), while at the local scale no causal relation is active.

It is important to note that both scales must not be simultaneously presented in the same situation To avoid this, it is adopted, in this work, the proposal implemented by Rickel and Porter (1997), in which it is considered that, when the fastest scale (local) is active, the slowest scale (regional) is considered to be stable. Inversely, when the slowest scale is active, the fastest is considered instantaneous, appearing to be stable. The Figure 7.22 shows that only the **regional scale is active**, while the local causality relations are not registered.

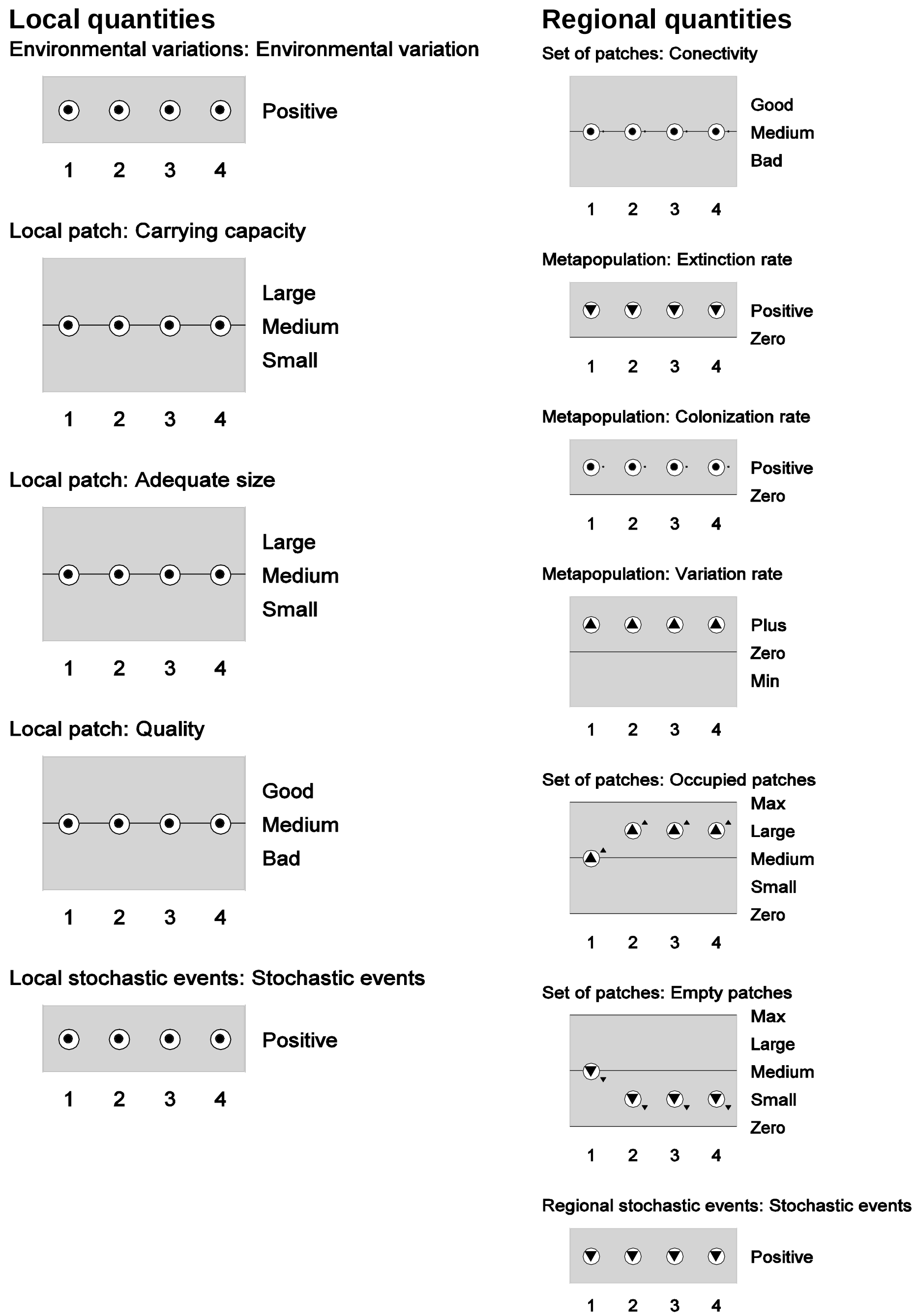


Figure 7.22. Value history diagram of the quantities, obtained in the simulation of the scenario Tscen01a active regional processes locals inactive. From state [2] the quality of the set of patches increases and influences the increase of the number of occupied patches.

The second scenario (Tscen01b) shows the opposite: the local scale is active and the regional scale inactive:

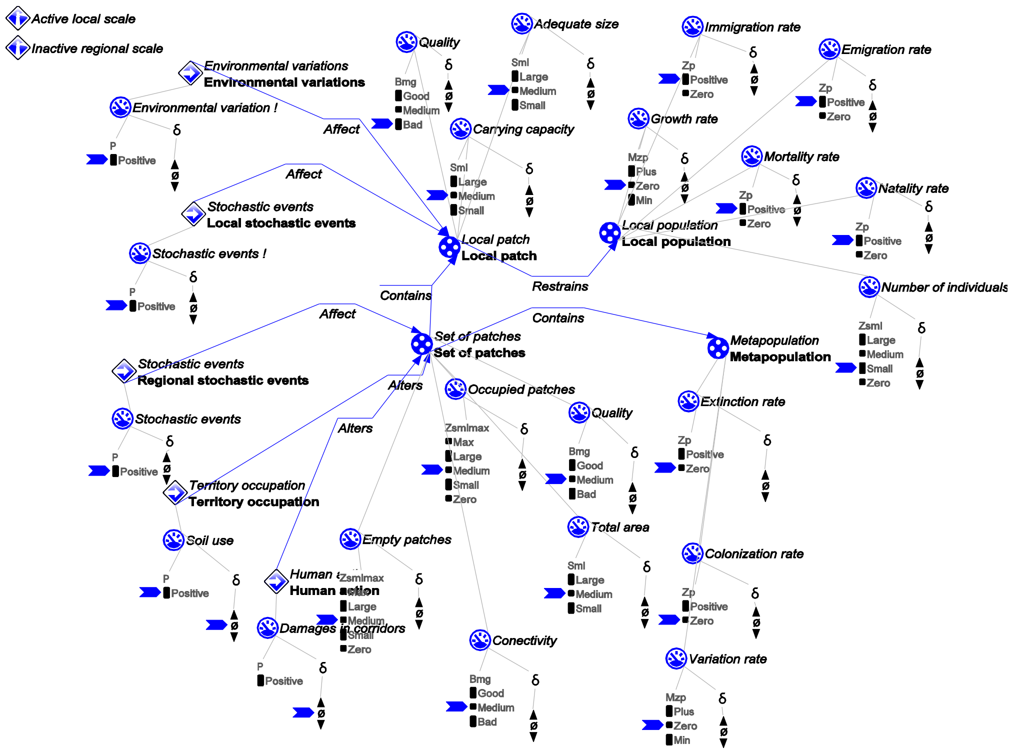


Figure 7.23. The second scenario (Tscen01b) the local scale active and regional scale inactive

Table 7.14. Resume of the scenario simulation

Scenario name	**Tsce01b Inactive regional processes, local active**
Complete simulation	[26 states]
Initial states	[1]
Final states	[18, 20, 22, 24, 25]
Relevant path	[1, 2, 5, 6, 16, 19, 22]
Behavior description	According to the values of the initial scenario, the local patch has a ‘bad’ quality, a ‘medium’ value of adequate size and a ‘medium’ value of carrying capacity. These quantities increase and local stochastic events have a positive decreasing value. In this simulation extinction and colonization rate have values equal zero and stable. All of the others regional quantities does not change.

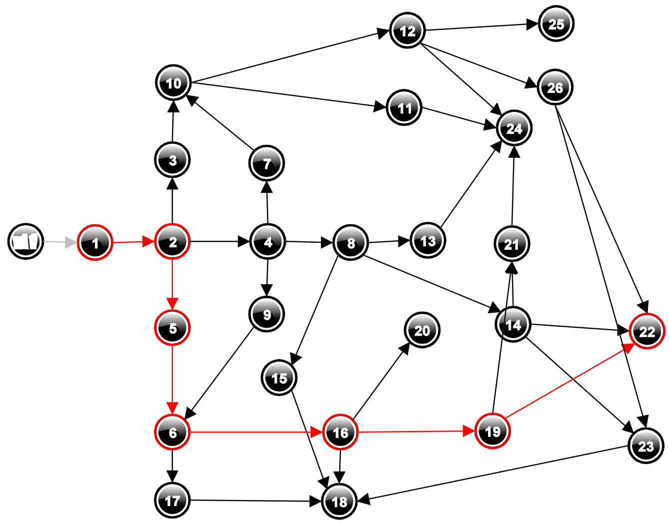


Figure 7.24. Behavior graph of the simulation initiated in the scenario Tscen01b inactive regional processes local active.

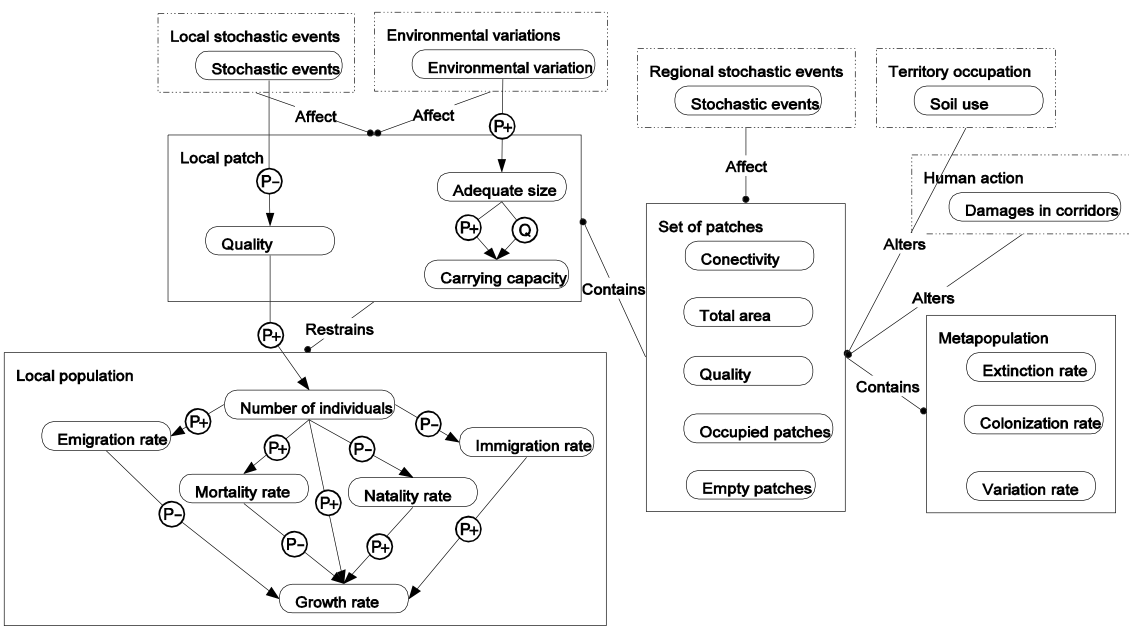


Figure 7.25. Causal model to the state [01] in a simulation starting with scenario Tcen01b active local processes regional inactive, being active only the local scale, as shown by the causal dependencies influencing the growth rate of the local population.

The quantities associated to the regional scale change in a slower pace, and are assumed to be constant. This is shown by the stability of all variables related to the metapopulation in Figure 7.26.

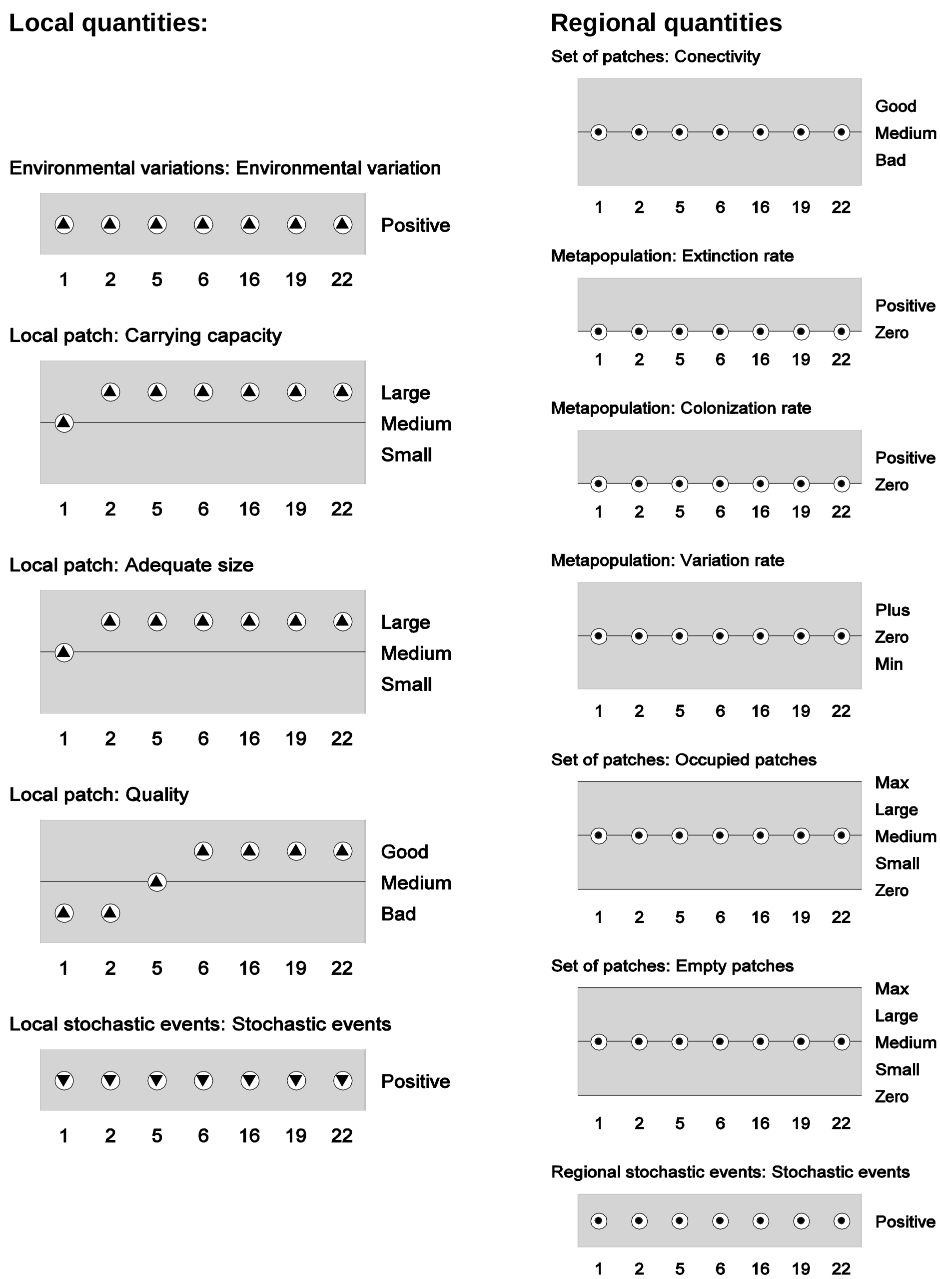


Figure 7.26. Value history diagram of the quantities obtained in the simulation of the scenario Tscen01b inactive regional processes, local active. Accordingly, quantities are changing in the left hand side column, and stable in the right hand side.

From state [5] onwards (Figure 7.26) the quality of local patches increases, as well as adequate size and carrying capacity of the local patch. These conditions result in the increase in the number of individuals, which will propagate to the other quantities, reaching growth rate.

7.6. Theoretical aspects of the model and topic

Laws and principles addressed in Metapopulation models:

Metapopulation is a mature theory

Remarkable in this model is the inspiration on diffusion

- Principles (Scheiner and Willig, 2008)
  1 (distribution in space and time is heterogeneous),
  2 (organisms interact with biotic and abiotic factors),
  3 (distribution depends on contingencies)
  4 (environmental conditions are heterogeneous in space and time)
  5 (resources are finite and heterogeneous in space and time)

- Laws (Dodds, 2009)
  Ecological diffusion (osmosis-like model; passive movement)
  Dominance of the Homo sapiens
  Fundamental properties of the populations (limits to growth, extinction)
  Population, resources and habitat heterogeneity (fragments of population, patch/matrix)
  Scaling (local and regional)

7.7. Conclusion of the topic

The models described in this topic represent basic mechanisms of a complex phenomenon, the dynamics of metapopulation. These models are supported by mature ecological theory. Two main approaches of how metapopulations behave were developed to represent a metapopulation that changes under the influence of colonization and extinction, and two populations in which one survives thanks to migration of propagules of the other population. The third model integrates current knowledge and others aspects in different temporal and spatial scales, local and regional. The results obtained for integrating the knowledge can contribute for an advance in metapopulation theory and for using this theoretical support to develop conservation measures.

8. Wind power

8.1. Topic and model metadata

Topic	**Sustainable sources and use of energy (wind)**		
Authors	Adriano Souza Gustavo Leite Paulo Salles	**Version(s)**	vs19
Models	Wind power LS6.hgp		
Target users	Stakeholders and students		

8.2. Topic rationale

8.2.1. Background

Wind is an indirect form of solar power and has emerged as a preeminent option of energy sources, in part because it is considered for many experts to be ecologically sustainable [Welch and Venkateswaran, 2009]. In fact, applications of wind to generate electrical power grew during the second half of the 20th century as the oil price increased during the 1970s, promoting intense interest in its value as a fuel-free, renewable energy source (Tavner, 2008), Figure 8.1 show the biggest offshore wind farm opened off Thanet in Kent, in 2010, and it’s expected to generate enough electricity to power 200,000 homes.

Figure 8.1. Source: http://www.bbc.co.uk/news/uk-england-kent-11395972

Worldwide energy supply insecurity, high oil prices and increasing levels of greenhouse gases (GHG) emission have prompted researchers to look for alternative energy sources to replace existing non-renewable energy sources such as fossil fuels (Lee *et al*., 2010). Wind has a number of advantages over most other energy sources. Wind farms require much less effort and time for planning and building than fossil fuel or nuclear power plants. Because the wind is free, clean and renewable, it constitutes a good choice in energy independence (Cunningham and Cunningham, 2007).

Based on that, the knowledge about the natural dynamics of this resource and the advantages of its exploration as energy source has a high value for making decisions in sustainable and integrate environmental management. Many countries (Figure 8.2) are now using and planning to use this kind of energy, exploring the potential of wind formation along the shore line, called sea breeze. Winds tend to be stronger over flat regions like large plains or the ocean, where no mountains or other surfaces constrain their movement. Offshore wind farms are more expensive to install than onshore ones, but offshore locations have greater potential for accommodating large projects. Further, highly populated regions, where power is most needed, tend to be near the coast (Riebeek, 2009), in Figure 8.3 it is possible to observe wind speed in Germany coastal zone of North sea and the location of in current service wind farms, as well the expansion plan with approved and planned offshore wind power plants to build.

In that way, Qualitative Reasoning (QR) offers a modeling paradigm which allows the explicit representation of the main process operating in the atmosphere that causes the Wind dynamics, providing a renewable supply of energy. Furthermore, the ontology provided by QR facilitates education about these processes, which will be useful for explanation to decision makers and stakeholders—those people who have a vested interest in the outcome of sustainable decisions (Nakova *et al*., 2007).

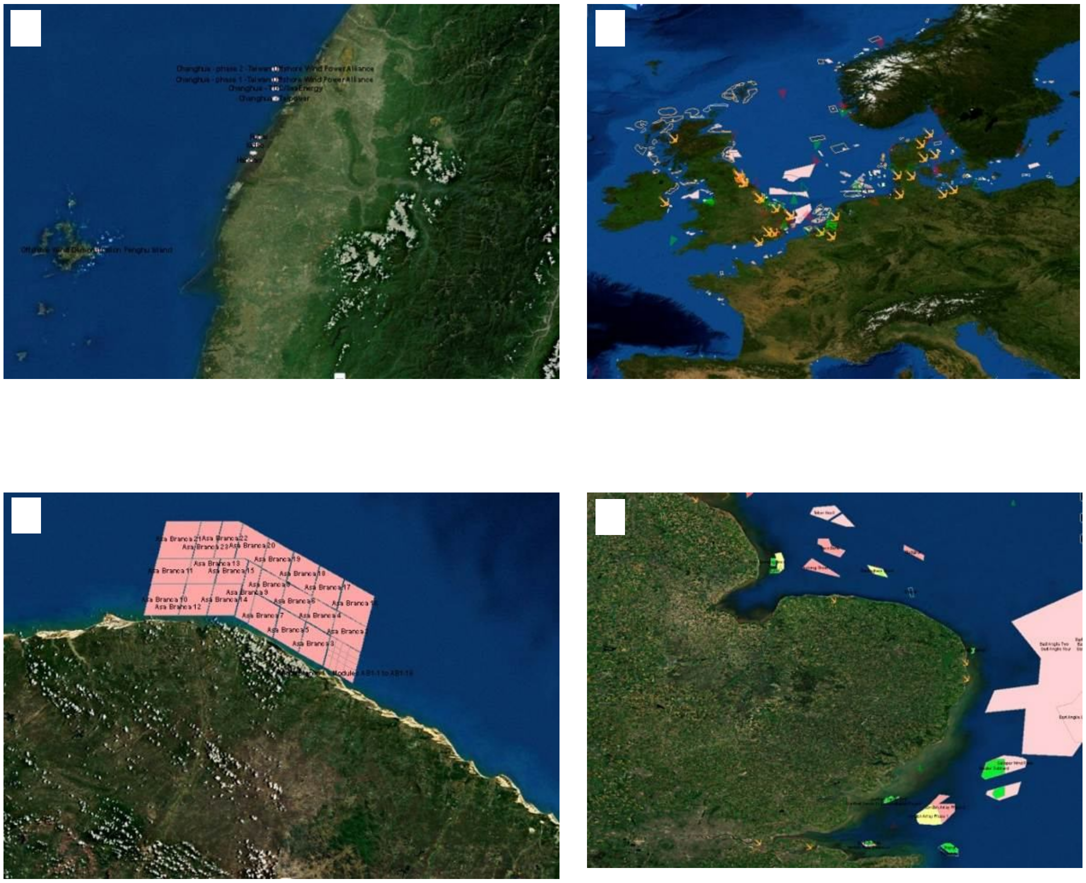


Figure 8.2. Examples of areas with offshore consented wind farms in operation or planned to be installed. Coast of Taiwan (A), North and Baltic seas (B), northeast coast of Brazil (C) and east coast England in North sea (D). Source: http://www.4coffshore.com/offshorewind/

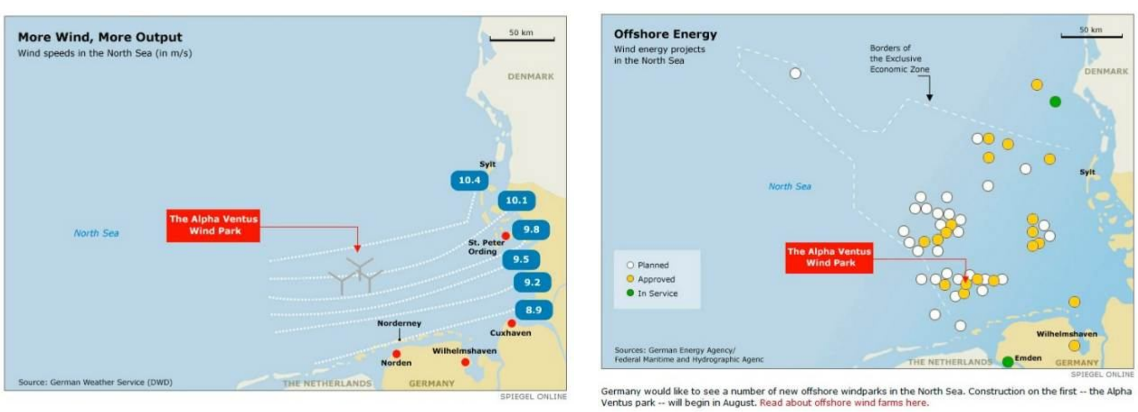


Figure 8.3. These maps show the wind speed in Germany coast of North Sea and current wind farms in service (green circles), approved (yellow circles) and planned (white circles). Source: http://www.spiegel.de/fotostrecke/fotostrecke-33595.html

Once we are dealing with a conceptual representation of an applicable alternative of power production, this qualitative modeling approach should provide an easy and friendly way of learning about the atmospheric dynamics in order to promote a better understanding of how wind power systems works. This approach will facilitate a whole view of the system, its structure and behavior by stakeholders (mainly the ones responsible for public administration) in order to make better decisions about energy and resources management. These features are offered by DynaLearn, an interactive learning system that integrates techniques developed in three areas: qualitative conceptual modeling, semantic technology and virtual pedagogical agents (Bredeweg. *et al.*, 2009).

Knowledge about the natural dynamics of wind resources and the advantages of its exploration as energy source has a high value for implementing sustainable and integrated environmental management.

8.3. Model

8.3.1. Concepts and goals

The presented model aims to describe the wind formation in coastal zone, its capacity to produce energy, the wind power conversion into energy for use by human activities.

The key issues and concepts for explaining how wind energy is produced are the following:

- Sun is the primary source of energy, whose radiation reaches the Earth's atmosphere.
- An important mechanism that often produces air movement occurs along the shoreline of continents and islands caused by the difference in specific heat of the land and sea water.
- Sea water has a higher specific heat than the land, i.e., the amount of energy required to raise the water temperature is greater than the energy required to increase the soil temperature (Figure 8.4).
- The atmospheric air pressure difference causes wind movement (air flow) from regions of higher pressure into regions of lower pressure. This way the wind mainly flows from the land into the sea during the night or from sea into the land during the day (Figure 8.4).
- Part of the kinetic energy of wind (wind power) can be transformed into rotational mechanical energy using wind turbines, which in turn convert this mechanical energy into electrical energy (Figure 8.5).

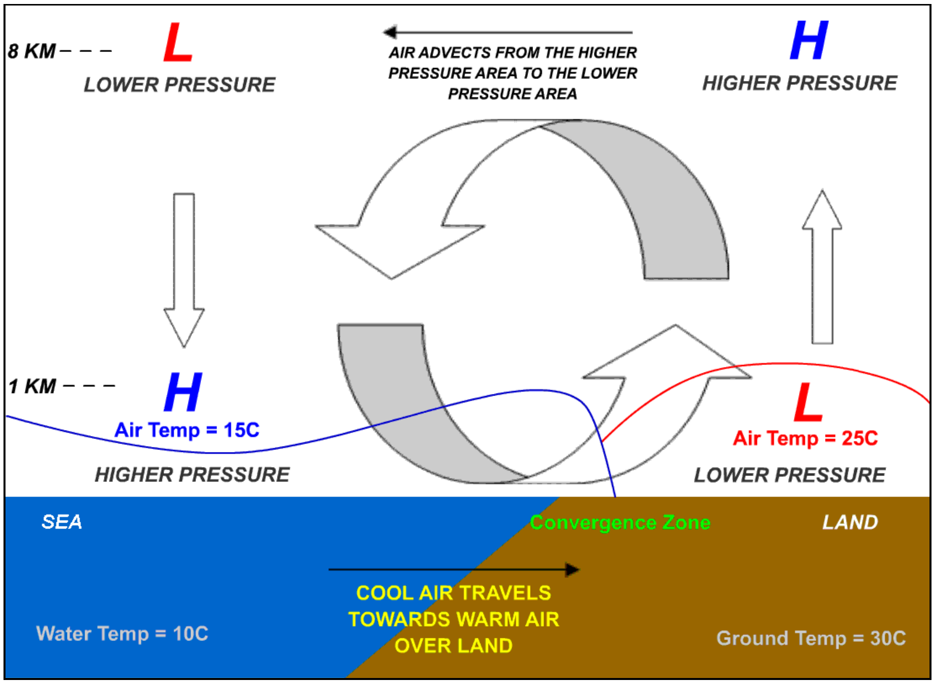


Figure 8.4. This diagram describes the dynamics of wind formation in shore lines of seas and lakes. Source: http://en.wikipedia.org/wiki/Sea_breeze

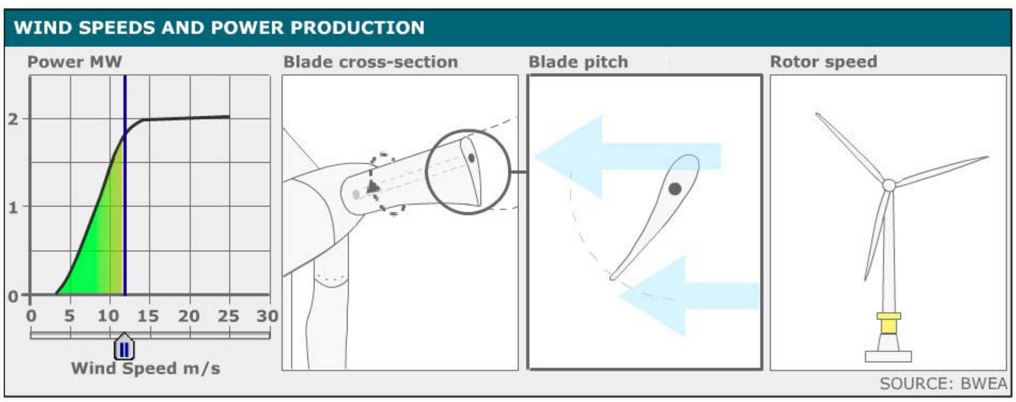


Figure 8.5. The picture shows the relationship between wind speed (m/s) and the amount of power (MW) produced and how wind affects blades to produce movement. Source: http://news.bbc.co.uk/2/hi/in_depth/629/629/7102346.stm

8.3.2. Modeling approach

This model can be used as a reference model for other people to use as source of inspiration to create other representations in which wind energy is part of the model. The main objective of this model is to represent the process of obtaining electric power using wind energy as a renewable source, namely the kinetic energy contained in wind, showing how this form of energy production is sustainable. This way, the model is able to capture the *basic mechanism* of wind formation and constitute a basic knowledge of a very and useful phenomenon on earth.

8.3.3. Model ingredients

Table 8.1. Entities, quantities and quantity spaces involved in the Wind Power model.

Entity	Quantity	Quantity Space
Atmosphere	Differential heating	*{Min, Zero, Plus}*
Sunlight	Light intensity	*{Zero, Night, Dawn dusk, Low, Medium, High, Midday}*
Wind	Air flow	*{Zero, Plus}*
	Kinetic energy	*{Zero, Plus}*
	Pressure difference	*{Towards sea, Zero, Towards land}*
Wind turbine	Rotation speed	*{Zero, Plus}*
	Energy production	*{Zero, Low, Medium, High}*
Sea	Heat accumulation	*{Zero, Plus}*
	Press atm surf*	*{Lowest, Low, Medium, High, Highest}*
	Temp atm surf**	*{Low, Medium, High}*
Land	Heat accumulation	*{Zero, Plus}*
	Press atm surf*	*{Lowest, Low, Medium, High, Highest}*
	Temp atm surf**	*{Lowest, Low, Medium, High, Highest}*

* Press atm surf: is the pressure of atmosphere at the surface of land or sea.

** Temp atm surf: is the temperature of atmosphere at the surface of land or sea

8.4. Model expression

8.4.1. Scenarios and simulations

The current version of the model has one scenario, which is presented in Figure 8.6. In this scenario, exogenous behaviors (Bredeweg *et al*., 2007) are assigned to the variable *Light intensity*, in order to represent sinusoidal behavior of light from solar incidence during 24 hours of a day, i.e., from midday (maximum light intensity) to zero (minimum light intensity). It is important to make a remark that it was considered as light intensity the amount of energy reaching atmosphere from the sun, then variations caused by clouds is not significant. This way, the simulation shows the transition from day to night and from night to day. Initial values of the other quantities are also represented in Figure 8.6.

The simulation with this scenario presented in Figure 8.6 produced a behavior graph with 295 states. Overall, the simulation shows that wind is caused by differential heating accumulation caused by different specific heat of land and sea water represented in the model by Heat accumulation and Differential heating. For example, considering the coastal region during the day, it is easy to observe that the land absorbs more heat than the sea water. Land's temperature becomes higher than the water's. As the heat dissipates to the atmosphere, the air above land also becomes hotter and less dense. So the warmer air rises, decreasing the surface air pressure over land.

This way, the air pressure over land becomes smaller than it is over the sea, producing neighbor zones with high pressure difference. Given that the wind flows from regions with higher air pressure to regions with lower pressure, during the day, wind flows from sea into land.

During the night the situation is the opposite, as the land loses heat faster than water, making the land temperature colder than the water temperature. This way the atmosphere above the land is denser than sea's and atmospheric pressure over the land becomes higher than the sea, creating an air flow from the land to the sea. Therefore the wind flows from the land into the sea during the night. Fishermen with wind driven boats leave to the sea early morning, and come back in the afternoon.

The causal model produced in state 3 of this simulation makes it easier to follow the changes (Figure 8.8). After running the simulation, it was obtained a state graph with 11 states, each path was inspected and we chose that one which is more similar to the behavior we want to show. The value history diagram of selected quantities confirms that (Figure 8.9). The behavior path presented in this Figure passes through the following states: [39 → 49 → 60 → 72 → 80 → 87 → 100 → 115 → 131 → 149 → 165 → 184 → 13 → 16 → 18 → 24 → 31 → 39].

In this behavior path, Light intensity decreases from medium to zero, increases from zero to midday and decreases again from midday to medium. Temperature at atmosphere over sea surface starts increasing, then decreases to zero, and finally increases to medium. Temperature at atmosphere over land surface has the opposite behavior, causing a pressure difference, which changes from towards land value to towards sea value, passing by zero value and then it goes from towards sea to towards land value.

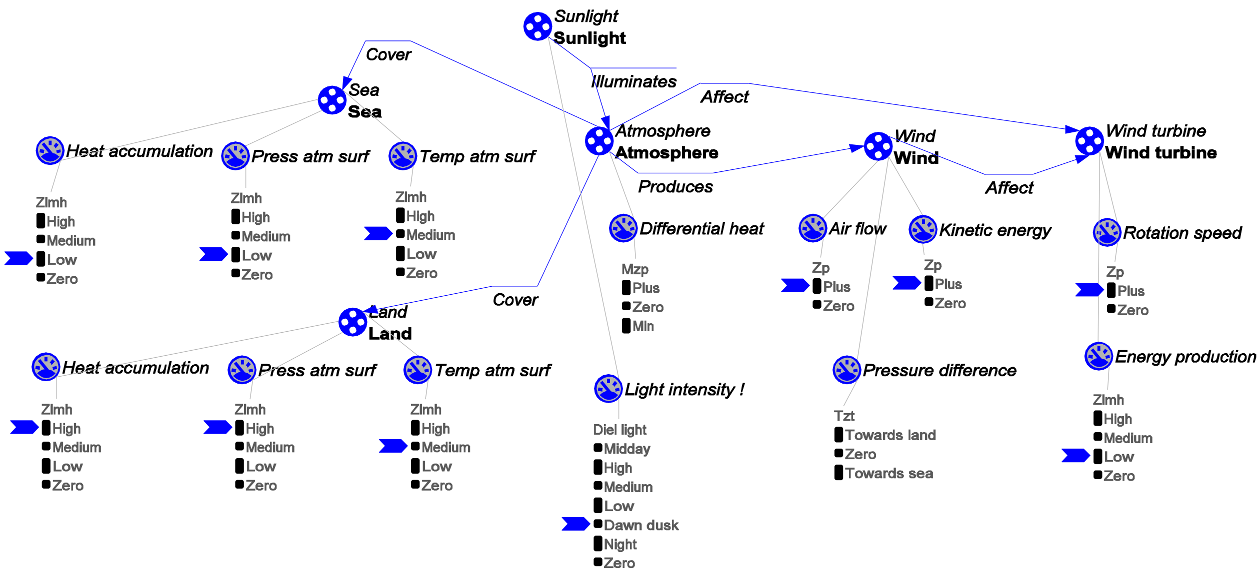


Figure 8.6. Scenario “Sce01 all influences” with initial values.

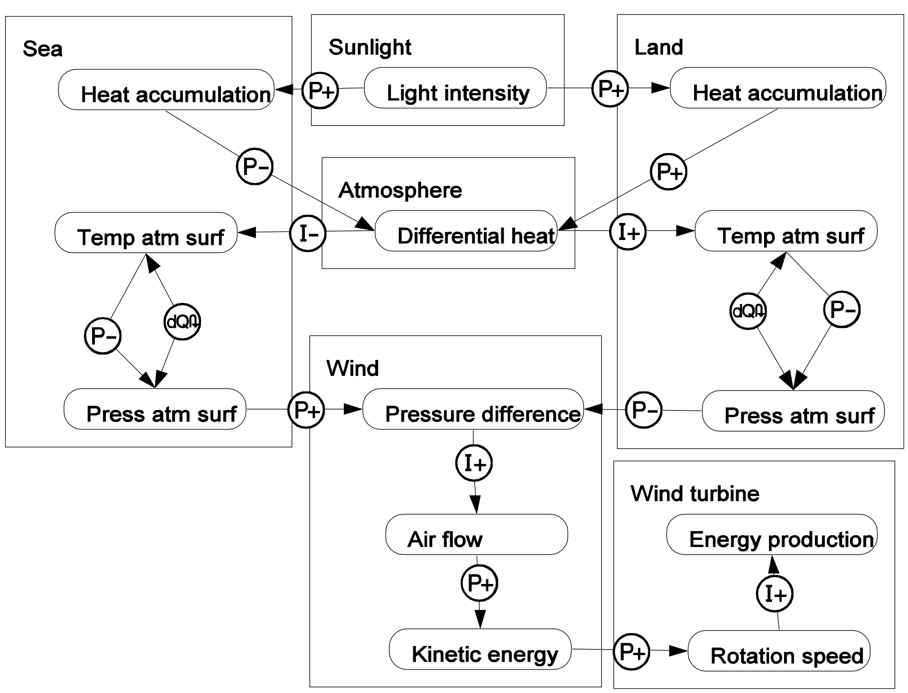


Figure 8.7. Causal model obtained in State 3 in a simulation with scenario Sce01 all influences

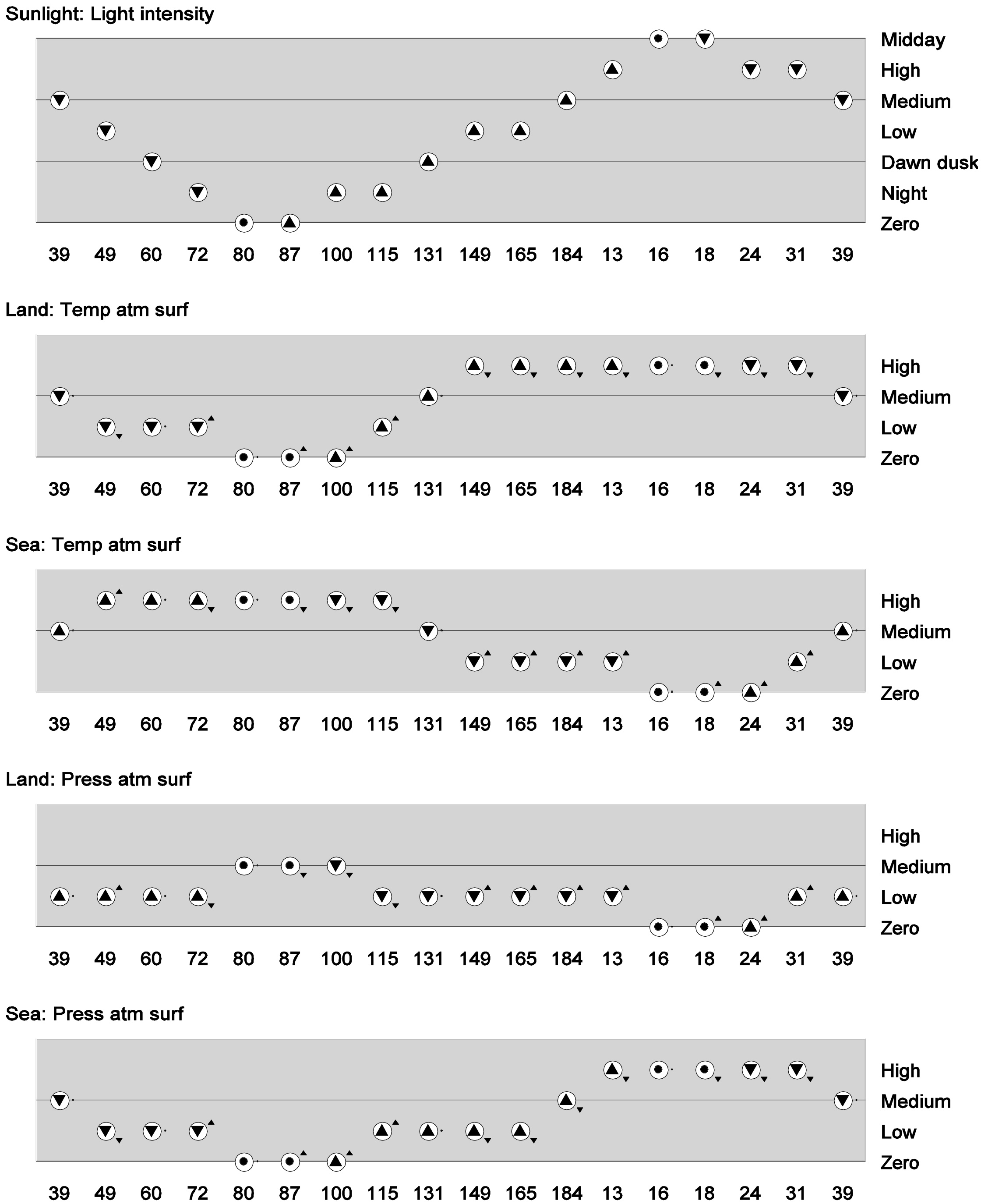


Figure 8.8. Value history diagram of selected quantities obtained in a simulation starting with the Scenario01 All influences.

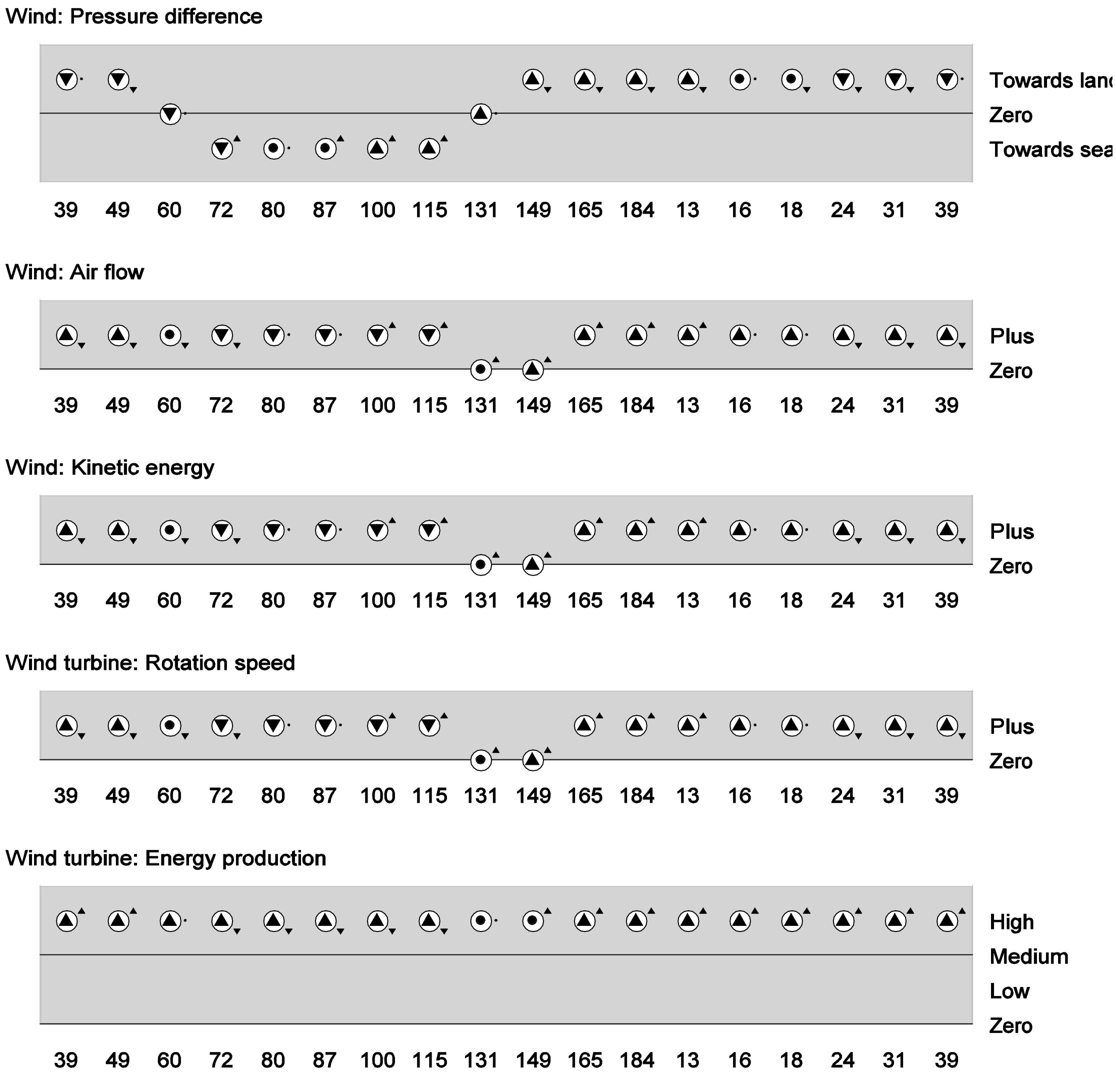


Figure 8.9. Value history diagram of selected quantities obtained in a simulation starting with the scenario01 All influences

8.5. Theoretical aspects of the model and topic

Laws and principles addressed in Wind power model:

Remarkable in this model are the laws from Physics

- Principles (Scheiner and Willig, 2008)

  2 (organisms interact with biotic and abiotic factors),

- Laws (Dodds, 2009)
  Dominance of the Homo sapiens
  Laws from economics
  Fundamental laws from Physics (specific heat, air pressure, energy transformation)

8.6. Conclusion of the topic

This section describes the development of a qualitative model to be used in learning about wind energy generation. The model successfully represented the wind dynamics in the coastal zone and how it can be used as a renewable source of energy.

The model shows the shift of wind direction in the coast zone, representing the phenomena of changing the air temperature caused by different specific heat of water and land, leading to different variation of air pressure, resulting in sea-land breezes, a very useful scenario chosen by engineers and stakeholders to place wind farms for energy production. In most part of the states, this simulation results in a scenario where the energy supply is positive, i.e., has a plus magnitude value, what requires a high energy production. It is an advanced model, as it is simple enough to be used by novice learners, but still shows the basic mechanism underneath the functioning of a system.

Ongoing work includes a preparation of evaluation material for secondary school students in building models, and this model can be used as a reference model for other people to use as inspiration, or re-use it to create other representations in which wind energy is part of the model, or use the model for DynaLearn to provide automated feedback to improve or fix models built in activities of Learning by Modeling.

9. Phytoremediation

9.1. Topic and model metadata

Topic	**Pollution Mitigation**		
Authors	Vanessa Tunholi Adriano Souza Gustavo Leite	**Version(s)**	Vs3
Models	Phytoremediation - *Eichhornia crassipes*		
Target users	Stakeholders and students		

9.2. Topic rationale

9.2.1. Background

Aquatic Macrophytes presents an important ecological role. In eutrophicated environments, these plants are extremely productive, especially if environmental factors are favorable, such as in tropical climates, with high luminosity incidence and low salinity. Many of those aquatic plants are known for their ability to accumulate pollutants, which can happen by physical-chemical interactions or by metabolism dependent mechanisms (Costa *et al.*, 2000). This way, the phytoremediation in contaminated areas is an alternative, capable of recruiting photosynthetic vegetal systems and its microorganisms, with the intention to detoxify degraded and polluted environments (Mees, 2006).

Eichhornia crassipes has great nutrient absorption and incorporation to its biomass potential, being utilized as water purifying mechanism. With 95% of water composition and intense growing, the water hyacinth is capable of absorbing more nutrients than necessary, according with the water fertility in which it is growing (Santos and Germano, 2011). This plant is also capable of absorbing heavy metals, being very important in filtration of water coming from industry (Santos and Germano, 2011).

The roots system of *E. crassipes* works as a mechanic filter that absorbs the suspended particulate matter (organic or mineral) (Mess, 2006). Beyond that, the water hyacinth cover facilitates the sedimentation mechanism, protecting from water movement (Pompêo, 2000). Based on this, the knowledge about the dynamic and advantages of the utilization of *Eichhornia crassipes* to detoxify and clean up aquatic environments has a high value in viable economic and ecological decision making.

Eichhornia crassipes has a wide geographical distribution, ability to colonize new environments and high growth rates, and so it is very attractive economically (Henry-Silva and Camargo, 2006). The net production of a single hectare was estimated to be 226.9 tons of dry weight per year (Greco and Freitas, 2002).

This species, which is native to the American tropics, is now found growing throughout the world, under tropical, subtropical, and, in some cases, temperate climatic regimes (Bock, 1969). The high reproductive capacity, rapid growth and extreme tolerance have given this macrophyte efficient mechanisms for reproduction and dispersion, rendering it able to form dense stands within a few months in a large variety of habitats, such as rivers, lakes, or reservoirs (Greco and Freitas, 2002). However, when they form large, dense colonization, macrophytes promote a lot of damage to the environment and multiple uses of reservoirs (Martins and Pitelli, 2005). In these situation, there is the need to reduce their population size by removing the plants or reducing the emission of pollutants.

Figure 9.1. *Eichhornia crassipes* in a Lake.

The ontology provided by QR facilitates education about these processes, which will be useful for explanation to decision makers and stakeholders—those people who have a vested interest in the outcome of sustainable decisions (Nakova *et al*., 2007).

Since we are dealing with a conceptual representation of an alternative for the removal of pollutants in water bodies, this model describes the dynamic of a polluted lake, to promote the understanding of how the introduction of *Eichhornia crassipes* works. The way it is addressed will facilitate the vision of the system as a whole, helping the decision makers manage, in an adequate form, the water resources that receive sewer. These features are offered by DynaLearn, an interactive learning system that integrates techniques developed in three areas: qualitative conceptual modeling, semantic technology and virtual pedagogical agents (Bredeweg *et al.*, 2009).

9.3. Model

Knowledge about the phytoremediation process and the advantages of the utilization of plants to clean up lakes has a great value to the implementation of the sustainable management of water resources, mainly in cities that do not treat their sewage. The key topics that are represented in the model are the effects of the introduction, biomass and growth rate of *Eichhornia crassipes* and further removal rate of this species on nutrient concentration in a lake. The control of *E.* crassipes is used this way to manage nutrient in the lake.

9.3.1. Concepts and goals

The presented model aims to describe the entrance of nutrients in a lake, the introduction of *Eichhornia crassipes*, the removal of nutrients by the roots of the plants and the withdraw of these macrophytes from the lake.

To represent and understand the phytoremediation process in polluted lakes, utilizing *Eichhornia crassipes*, and its effects in the amount of nutrients.

9.3.2. Modeling approach

The main objective of this model is to represent the process of phytoremediation using Eichhornia crassipes to remove nutrients of the lake, showing that, at the time these macrophytes can be used to clean up the lake, they must be withdrawn when the biomass reaches the carrying capacity. If not removed in the appropriate time, *Eichhornia crassipes* can be the source of pollution. This way the model constitutes a basic knowledge, with feedbacks, of a useful mechanism to human populations.

9.3.3. Model ingredients

The phytorremediation model involves 2 different entities, 1 agent, 2 configuration types, 9 quantities, 8 model fragments and 2 scenarios. All the entities and agents are listed in Table 9.1, and the quantities in Table 9.2. Each of the processes and their associated relations captured in this diagram are explained in the following sections.

Table 9.1. Agents and entities in the phytorremediation model.

Entity or agent	Description
Lake	The ecosystem of interest
Eichhornia crassipes	This population is responsible for phytorremediation
Human population (Agent)	Represent the agent that send sewage into the lake

Table 9.2. Quantities in the phytorremediation model.

Quantity	Description
Amount of nutrient	The amount of nutrients dissolved in the water
Amount of sewer	The amount of sewage dissolved in the water
Nutrient variation rate	The current amount of nutrient in the water (the amount of nutrient less removed nutrients)
Biomass	The current biomass of a population, used to represent the size of the population
Amount of absorbed nutrient	The amount of nutrients removed by *Eicchornia crassipes*
Introduction rate	The process of introduction of *Eichhornia crassipes* in the water
Eichhornia removal rate	The process of biomass removal, due to the growth and increase in the number of individuals of *Eichhornia crassipes*
Growth rate	The process of biomass increase, due to birth or positive growth of individuals of *Eichhornia crassipes*
Sewer emission rate	The amount of sewage sent to the lake by humans

9.4. Model expression

9.4.1. Model Fragments

Exogenous quantities

The agent *human population* represents the responsible for the sewage production. This agent is not part of the system being modeled, but it affects it. It influence on the system is modeled by its associated quantities *Sewer emission rate.*

Introduction rate, quantity associated with the entity *Eichhornia* crassipes, is also considered exogenous and is driven by the exogenous pattern “decrease”. This makes the introduction stop, when *E. crassipes* has already been introduced. When this variable is active, it positively influences (I+) Biomass.

Nutrient variation rate

The *nutrient variation rate* is determined by the *amount of sewer* in the lake and the *amount of nutrient absorbed* from the lake. In this model, the *biomass* is proportional to the *amount of absorbed sewage* by *E. crassipes* and the *sewer emission rate* influences the *amount of sewer* in the lake. The *Nutrient variation rate* influences the *amount of nutrient*.

Two other variables influence the dynamics of the system: *Growth rate* and *Eichhornia removal rate*. *Growth rate* represents the rate of increase of *biomass*. This quantity has a positive influence (I+) on *Biomass,* when biomass is greater than zero. When biomass is equal or greater than *Carrying* capacity, the derivative of *Growth rate* becomes descending. This fact is represented using a separate model fragment with a conditional value assignment (Figure 9.3).

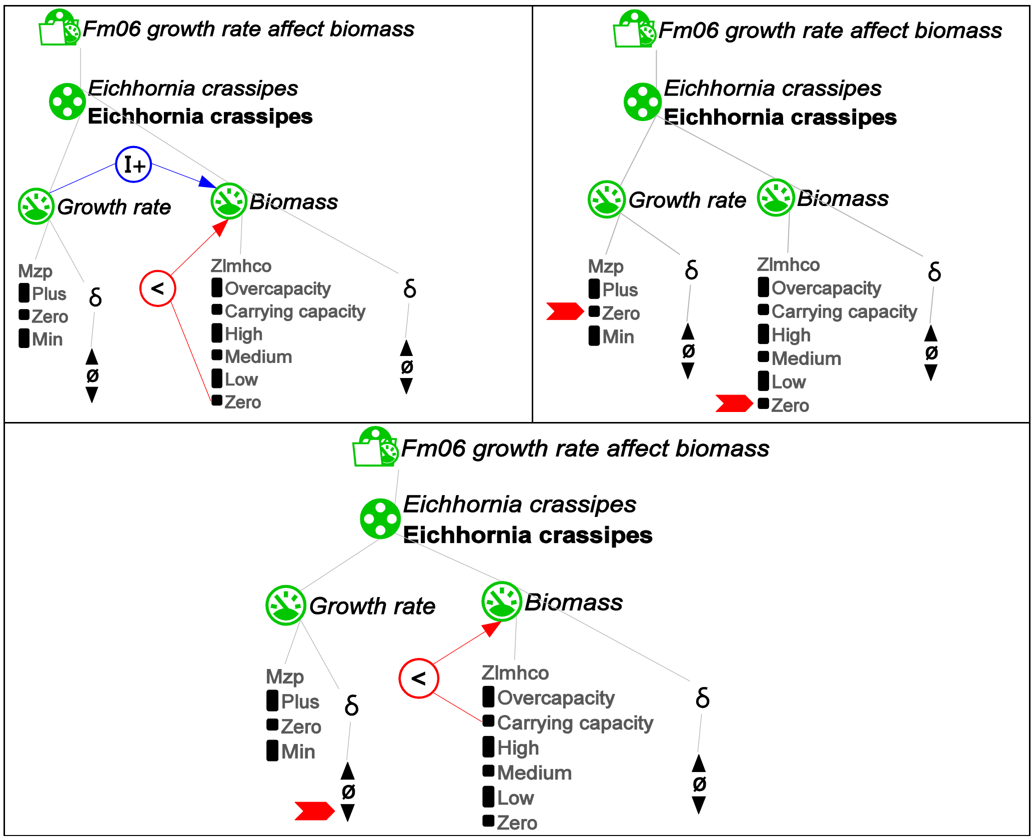


Figure 9.3. Model fragments with a conditional value assignment.

When the *amount of nutrient* is higher than *critical*, *Growth rate* is influenced by the *amount of nutrient*. This fact is represented using a separate model fragment with a conditional value assignment (Figure 9.4).

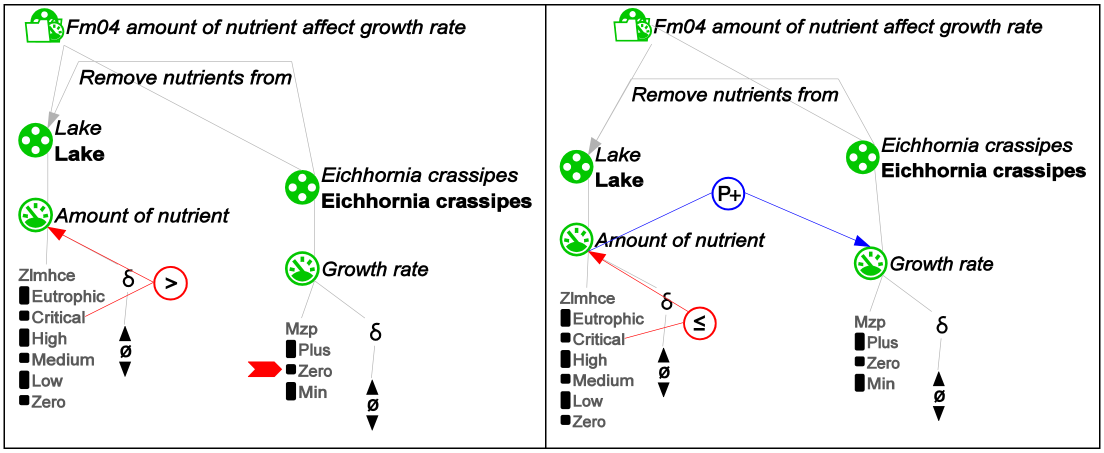


Figure 9.4. Model fragments with a conditional value assignment.

Determining biomass for Eichhornia crassipes

For *Eichhornia crassipes*, nutrients are the major factor that determines biomass. The relationship between *amount of nutrient* and *Growth rate* of *E. crassipes* is straightforward: the higher the *amount of nutrient*, the higher the *Growth rate*, and consequently, higher *biomass*. A high level of biomass is only possible if amount of nutrient is favorable.

Eicchornia remotion rate

When a population of *Eichhornia crassipes* becomes very large, it is necessary to remove it. In the model, the removal is said to occur if the *Biomass* of a population is equal or greater than *carrying capacity* and the *Eichhornia removal rate* has a negative influence on *Biomass*. When the removal does not happen, the *necromass* increases the amount of nutrient and biomass becomes a source of pollution, causing a series of problems for water users. We have chosen not to model the necromass, because its influence and biomass influences have an ambiguous effect, hard to resolve. This fact is represented using a separated model fragment with conditional knowledge (Figure 9.5).

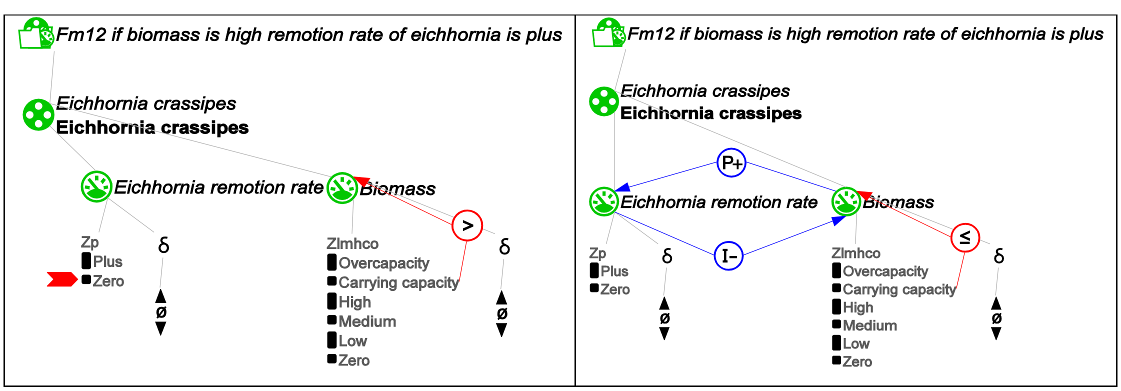


Figure 9.5. Model fragments with a conditional value assignment.

9.4.2. Scenarios and simulations

The first scenario, presented in Figure 9.6, illustrates how the amount of nutrients in the lake is quantified. The amount of absorbed sewage and the sewer emission rate have exogenous behavior (increase and steady, respectively).

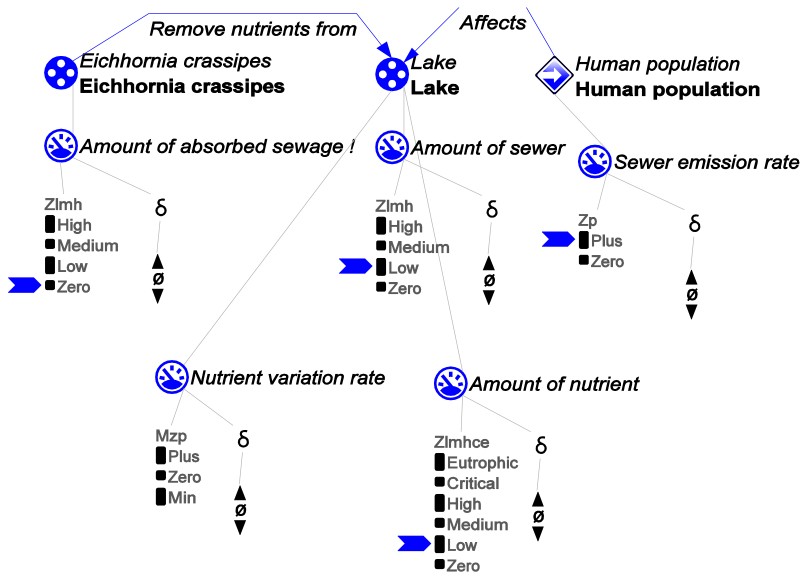


Figure 9.6. Scenario 1with initial values of quantities

The state-graph of this simulation has 51 states. It has a single starting state where *Amount of sewer* and *Amount of nutrient* is *low*, *Amount of absorbed sewage* is *zero* and *Sewer emission rate* is *plus*.

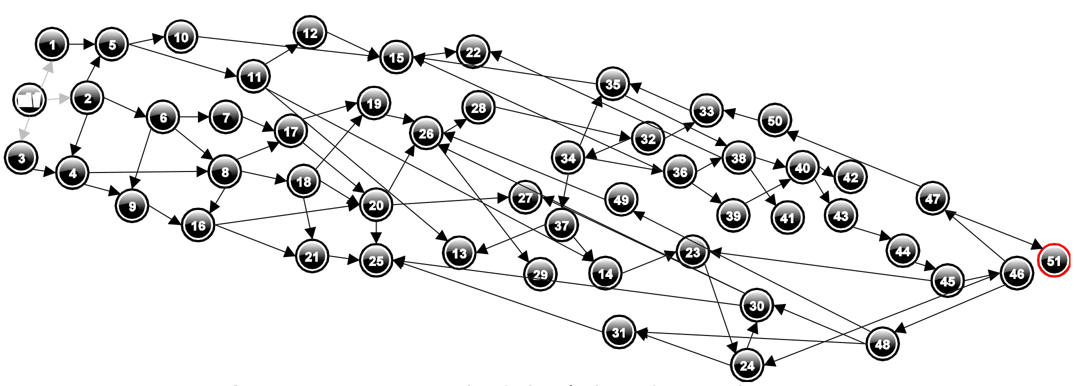


Figure 9.7. State-graph of simulation of scenario 1.

In the simulation, paths can be distinguished where *amount of nutrients* reaches *eutrophic*, as well as paths where this variable reaches *eutrophic* and decreases to *zero*, and paths where it reaches *eutrophic*, decreases to *zero* and increases to *critical*. *Amount of nutrient* is influenced by *nutrient variation rate* (I+) that assumes a similar standard. When the *nutrient variation rate* decreases, the *amount of nutrient* also decreases and when the first variable is plus, the second one is increasing. Figure 9.8 shows the value history diagram of a single path. In this path, *amount of sewer* and *amount of absorbed sewage* increase almost simultaneously. The *amount of nutrient* becomes *eutrophic* (state 2, 4, 8, 16, 20, 26 e 28) and drop back to *zero* (state 32, 33, 35, 38, 40 e 42) as *nutrient variation* decreases to *zero* and *minus*.

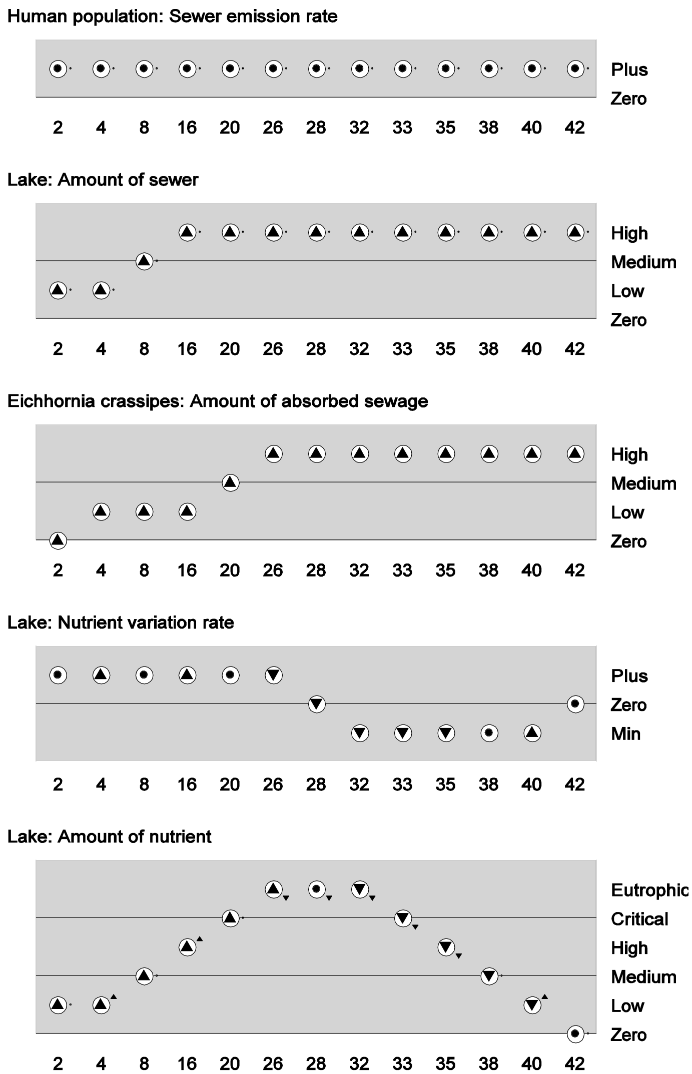


Figure 9.8. Value history diagram of a single path, scenario 1.

This scenario concerns the behavior of *Eichhornia crassipes* in a polluted lake. The *amount of nutrient* is affected by the behavior of *amount of absorbed sewage*, which removes nutrients from the lake. The conclusion that can be drawn is that to fight the eutrophication, it is necessary to reduce the emission of sewer or to increase the amount of absorbed sewage.

Full causal phytorremediation mechanism

Scenario 2 shows (Figure 9.9) the full causal phytorremediation mechanism. Initially, the lake is eutrophic and the *introduction rate* of *Eichhornia crassipes* starts with the value 'plus'. This variable has exogenous behaviour (decrease), just like *sewer emission rate*.

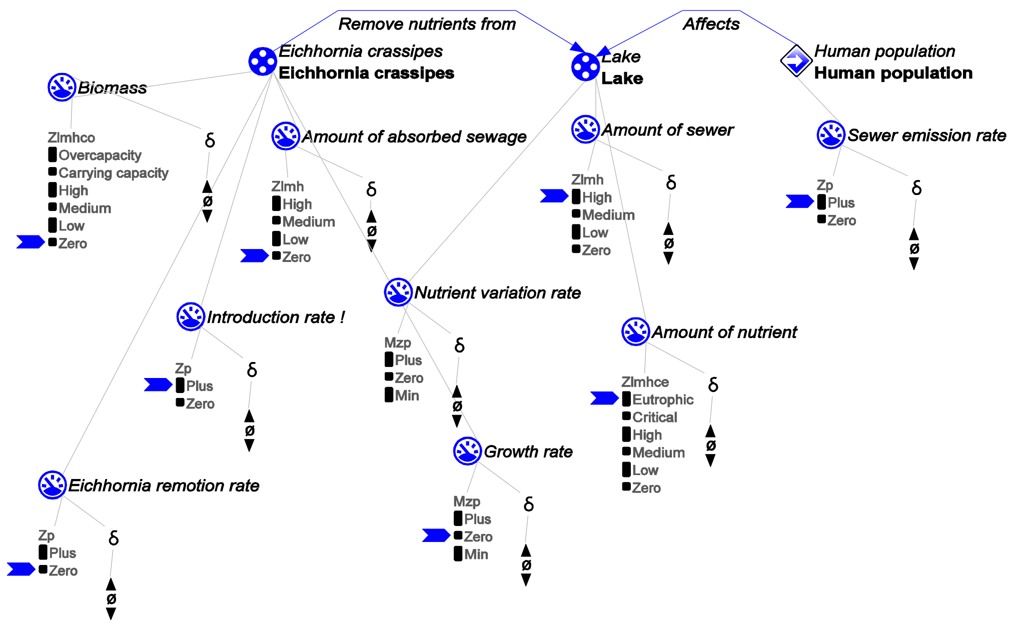


Figure 9.9. Scenario 2.

The state-graph for this simulation is shown in Figure 9.10 and a value history in Figure 9.11.

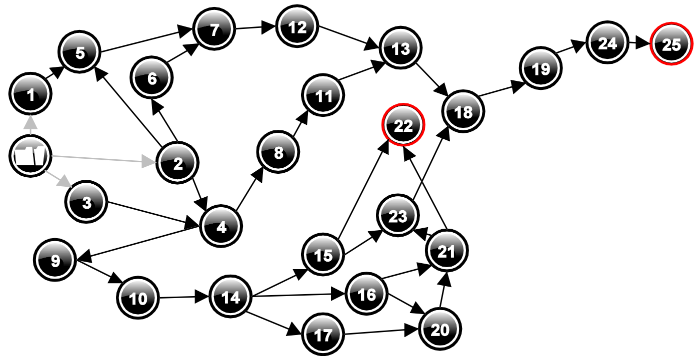


Figure 9.10. State-graph of simulation of scenario 2.

In state 1, *amount of nutrient* is *eutrophic* as consequence of *high amount of sewer* and no *amount of absorbed sewage.* In the same state, *Eichhornia crassipes* is introduced and in the next state a*mount of absorbed sewage* increases. The *growth rate* becomes *plus* in state 5. As *biomass* increases, *amount of nutrient* decreases, and when biomass reaches *overcapacity*, the *Eichhornia remotion rate* becomes plus. This happens in state 18. Two states after (24) *biomass* starts to decrease, reaching the carrying capacity. When *amount of nutrient* decreases, the *growth* rate also decreases (Henry-Silva and Camargo, 2006).

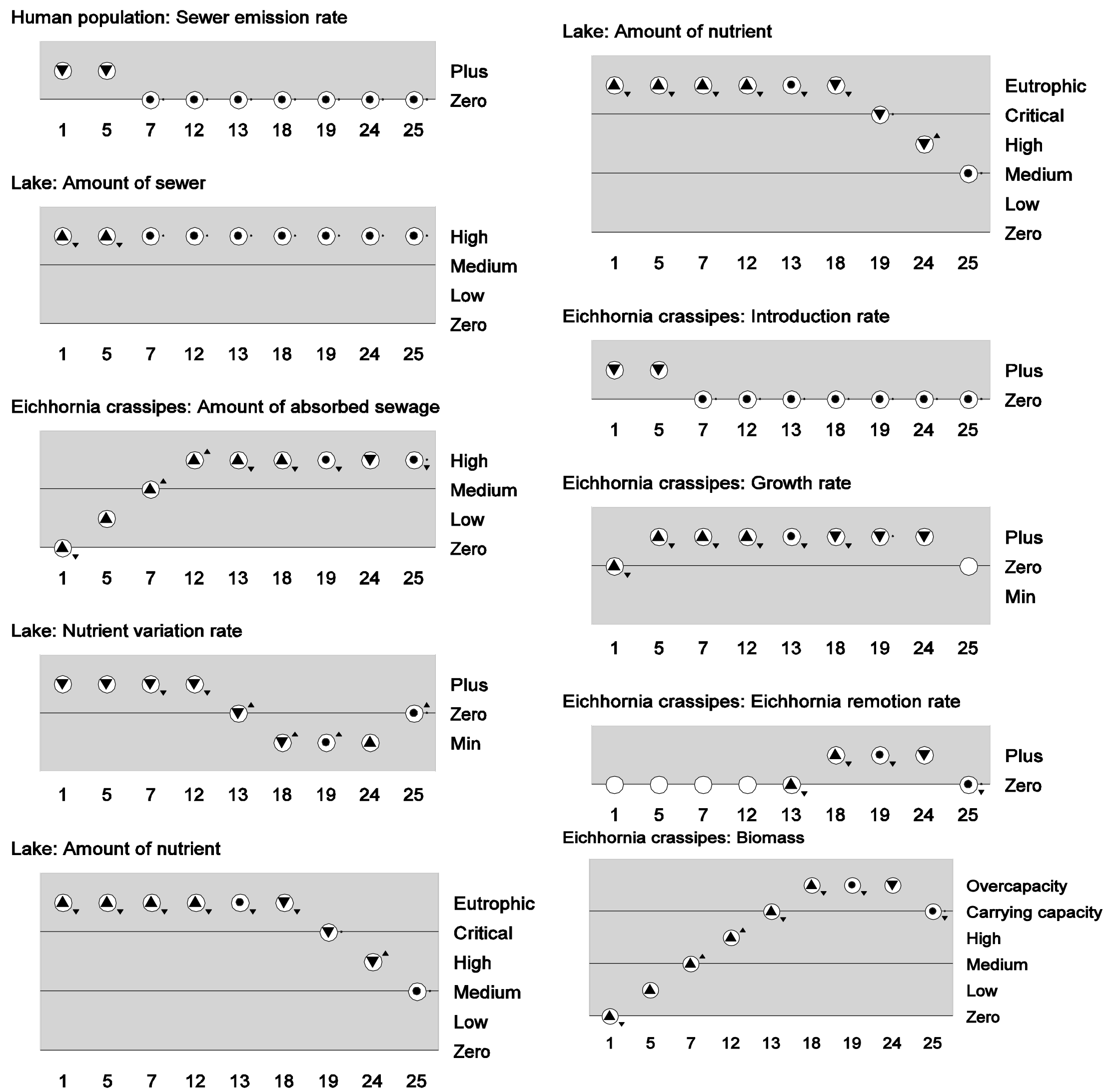


Figure 9.11. Value history diagram of a single path, scenario 2.

This scenario illustrates the phytorremediation mechanism, with the introduction of *E. crassipes* in a eutrophic lake, removal of the nutrients and, finally, removal of the macrophytes.

The set of scenarios focuses on introduction and removal of *E. crassipes* to illustrate the important effects of these factors on nutrient reduction.
Future work could also focus on increasing biomass, leading to an increase in the amount of nutrients (caused by necromass), to illustrate the importance of the management, removing

biomass. Old leaves of *E. crassipes* become senescent gradually and decompose, while still attached to the plant, allowing time for nutrients translocation for new growth, resulting in the conservation limiting nutrients (Greco and Freitas, 2002).

Without management, in dams, *E.* crassipes tend to cover the surface with danger of being absorbed or clog up the protection bars systems of turbine systems that generate electricity (Pitelli *et al.*, 2009). Large blocks of plants that move are hazardous to navigation (Pitelli *et al.*, 2009). The rapid growth of this species also increases evapotranspiration and brings a negative effect on recreation (Greco and Freitas, 2002).

Oxygen should be included in future studies, as a quantity of the entity lake, since the decomposition of *Eichhornia crassipes* occurs rapidly with a high consumption of this element (Negrisoli *et al.*, 2006). With this, other people could be affected negatively. It is important to also include them in future work.

The disadvantage of the use of introduction rate as exogenous quantities is that the introduction does not occur only when the amount of nutrients is *eutrophic* and it does not cease to occur when the *amount of nutrient* is lower. Future research should implement the *introduction rate* not as exogenous quantities, but influenced by amount of nutrient.

Some authors found a trend of higher occurrence of aquatic plants floating in water with higher turbidity. Thus, this element could be added to the model, as a quantity of the entity Lake, influenced negatively (P-) by the biomass of *E. crassipes.* (Carvalho *et al.*, 2005). Those macrophytes are effective in reducing turbidity mainly due to its great root development (Henry-Silva and Camargo, 2008).

The temperature could also be a quantity that influences *Eichhornia crassipes* biomass, because the plants grew faster under the warmest temperature regime provided (27.6° C) (Bock 1969; Greco and Freitas, 2002). The low temperatures may have negatively influenced the growth rate (Bock 1969; Greco and Freitas, 2002).

As the processes of nutrient removal by *Eichhornia crassipes* occur not only by direct absorption, but also by a combination of physical mechanisms, biological and chemical agents, such as sedimentation and transformation of nitrogen by bacteria (Henry-Silva and Camargo, 2008), it would be important to include those in the model.

Future work could also focus on the longevity of *Eichhornia crassipes*. This quantity would be influenced negatively by biomass: their longevity decline with density rise (Greco and Freitas, 2002).

Another quantity that can be included in future works is pH of water. The pH of water is higher in areas without *E. crassipes* (Martins and Pitelli, 2005). This fact is related to the respiratory activity of the root system, which produces carbon dioxide, with the interception of sunlight, which prevents the photosynthetic activity, and to death and decomposition of plants (Martins and Pitelli, 2005).

9.5. Theoretical aspects of the model and topic

Laws and principles addressed in Phytorremediation model:

Biorremediation is a well-known technique that is being recognized as a clean way to solve problems.

Remarkable in this model is the importance of educated human actions to introduce and to remove organisms in order to control nutrient concentration.

- Principles (Scheiner and Willig, 2008)
  2 (organisms interact with biotic and abiotic factors),
  3 (distribution depends on contingencies)
  4 (environmental conditions are heterogeneous in space and time)
  5 (resources are finite and heterogeneous in space and time)
  6 (all organisms are mortal)

- Laws (Dodds, 2009)
  Dominance of the Homo sapiens
  Fundamental properties of the populations (exponential growth, limits to growth)
  Population, resources and habitat heterogeneity
  Nutrient cycling

9.6. Conclusion of the topic

A qualitative reasoning model of phytorremediation, using Dynalearn, was presented. This model includes the use of *Eichhornia crassipes* in eutrophic aquatic ecosystem that receives sewer constantly. With the increase in the amount of nutrient in the lake, the growth rate and biomass of *E. crassipes* increase and it becomes necessary to remove part of it.

The model produces valid simulations, illustrating how the macrophytes can absorb the pollution and the effect of the removal of biomass, keeping the population within the range where its beneficial effects to the environment outweigh the harmful effects.

10. Discussion and final conclusions

- Models are idealizations and formal representations of real world systems. As such, they are not meant to capture all the details, but only fundamental knowledge to demonstrate basic mechanisms that support understanding, prediction and explanations of the system behavior.
- Theories encompass causal representations of observed behavior. Model simulations can express the system behavior under different circumstances, so that they can be seen as ‘experiments’ with the system of interest. As put by Caswell (1988), models are to theoretical studies as experiments are to empirical studies.
- Advanced models in DynaLearn capture a broad range of laws and theories about environmental systems. This way, they embody hypotheses, that sometimes are verbally described, and others are formalized in different languages, such as the metapopulation models, which are thoroughly defined in mathematical terms.
- Thinking about theoretical aspects of environmental sciences and presenting causal explanations to system behavior opens a new way of thinking about the curriculum contents. Therefore, the use of models in educational contexts may have a significant impact on science understanding use of qualitative models in educational contexts may have a significant impact on science understanding. The learning by modeling approach can further develop a better understanding of the domain knowledge, based on ‘hands on’ experience.

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